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SVIC NOTES

Perceptions in Damping

A review of the Vibration Damping Workshop II, which was held this past March, appears on other pages of this issue. I would like to use this set of SVIC Notes to discuss my perceptions of the technical content of this meeting.

Judging from the papers that were presented the emphasis was on using the various damping mechanisms to control the vibrations of large space structures, their experiments, and their sensors. Many of these papers emphasized the structure-control system interaction which has become important because the supporting structures for many of the sensors or experiments will be large and flexible so that the operating frequency of their control systems will coincide with one of their natural frequencies. The role of damping will be to control the vibrations of these support structures so they do not interfere with the proper functioning of the sensors or the experiments. Many of the papers raised some interesting, if not controversial, questions. For example, how much structural damping is necessary to ensure the proper operation of active control systems? Associated with that question is how much damping is available in monolithic structures, and in built-up structures? But, even more important, what damping mechanisms are operative in built-up structures? This is important because some damping mechanisms may not be operative in built-up structures in Space.

Traditionally, much of the literature on damping has concerned the development and the use of viscoelastic material damping treatments to reduce potentially damaging levels of vibrations. But, many of the papers on the applications of damping in this meeting were on the use of passive damping, in the form of additive treatments of discrete devices, to control the relatively low levels of structural vibrations that might be encountered in future space vehicles or space structures. Although the use of damping to control such low levels of vibrations seemed to be emphasized, it does not mean the traditional applications of damping are less important, or of less interest. Several papers were on the more traditional role of damping. The papers that were presented on the RELSAT program brought out the effectiveness of designed-in additive damping treatments for keeping vibration inputs to spacecraft equipment at safe levels.

Historically, the properties of damping materials and the methods for measuring them have been subjects of great interest. Many of the papers that were presented at this meeting reflected a continuing interest in materials properties. The papers that were presented on the properties of viscoelastic materials for damping treatments emphasized the importance of using the proper test methods to obtain valid materials properties data, and the importance of the compatibility of the material with the space environment. Since composite materials are expected to be used extensively in the construction of future space structures their damping properties will be important in controlling vibration inputs to sensors and experiments. The papers that were programmed in the session on composite materials were on the damping mechanisms in composite materials, the damping properties of composite materials, and the methods for predicting and measuring the damping properties of composite materials.

The participants, and those who organized and managed this meeting, are to be commended for the hard work that led to a successful meeting.

R.H.V.

EDITORS RATTLE SPACE

The Balance Between Computation and Testing

In recent years the balance between computation and testing in individual research and development projects has improved. Years ago investigators were oriented specifically to computer modeling or to laboratory testing. Arguments prevailed on which research was more fruitful. Fortunately, today researchers seek a balance between the two activities and use both technologies for confirmation and enhancement of each other. Each activity has some advantages and researchers have found that when they are applied together a much better product results.

It is interesting to note that many projects result in computational and experimental work; however, the results are rarely published in the same paper. Several factors are involved in this unfortunate problem. Page length limitations are imposed by many journals. Special interest such as theory, computation, or testing are catered to by many journals. Not much effort is placed in obtaining complete works. It appears that publishers are more interested in quantity than quality. It is a known fact that page length limitations increase the volume of material published. The same technology is published in a series of articles with repetition in introductory and background material. Splitting research reporting is inefficient. This all leads to more pages published per research project, increased library costs, and increased difficulties in obtaining and reading the literature.

This issue of the DIGEST contains the program for the 57th Shock and Vibration Symposium which results in the publication of the Shock and Vibration Bulletin. The Symposium and its related publication the Bulletin have been, over the years of their existence, a balanced forum for reporting experimental and analytical work. In fact the breadth of work reported goes from finite element modeling to environmental testing. If the Shock and Vibration Information Center has managed to avoid the page limitation inefficiency and the segregation of technology, why can't others? Is it the first priority of a publisher to make money or to serve the technical community?

R.L.E.

RANDOM TESTING WITH DIGITAL CONTROL — APPLICATION IN THE DISTRIBUTION QUALIFICATION OF MICROCOMPUTERS

C.W. deSilva*, S.J. Henning**, and J.D. Brown**

Abstract. This article is concerned with the rationale for using random testing for distribution qualification. The test procedure is described, the principle of operation of digital controllers for random testing is outlined, and several commercial systems are evaluated with respect to the capabilities, specifications, and hardware and software features.

Dynamic testing refers to the process of applying a specified dynamic excitation to a test object and monitoring the resulting response. The technique is used primarily for design development, quality control, and qualification. A well-designed product of good quality that has been approved for normal operation may still require qualification for a special application or environment. In seismic qualification, for example, a test object is qualified for a specified seismic environment.

The term distribution qualification is used to denote the process by which the ability of a product to withstand a clearly defined distribution environment is established. Dynamic effects on the product due to handling loads, characteristics of packaging, and excitations under various modes of transportation (truck, rail, air, and ocean) must be properly represented in the test specifications used for distribution qualification. If a product fails a qualification test, corrective measures and subsequent requalification are necessary prior to commercial distribution. Product redesign, packaging redesign, and modification of existing shipping procedures might be required to meet qualification requirements.

Often the necessary improvements can be determined by analyzing data from prior tests. Proper distribution qualification will result in improved product quality (and associated reliability and performance), reduced waste and inventory problems, cost-effective packaging, reduced shipping and handling costs, and reduced warranty and service costs.

SINE TESTING AND RANDOM TESTING

In sine testing, a sine-sweep excitation is applied to a test object. The amplitude-frequency profile of the sweep as well as the sweep rate must be specified. Advantages of sine testing include simplicity and low cost. Even though a sine sweep is able to generate severity levels and frequency content present in a real environment, it is not an accurate representation of the actual dynamic environment of product distribution. The actual distribution environment is random in nature; the sine test is a deterministic one. A sine-sweep test signal is completely determined by amplitude and frequency values with respect to time. A constant sweep rate is commonly used. On the other hand, a random signal is defined by statistical representations such as probability distribution or power spectral density (psd); they cannot uniquely determine what the test signal would be. The contrast is shown in Figure 1

Although test level, sweep frequency range, and sweep rate can define a sine-sweep signal, the probability density curve of the random signal provides only the probability with which the signal amplitude would fall within a given range of values. The actual value at a particular time is unknown until the random signal is generated by actuating the random process. Even then it is but one sample of the random process. It is unlikely that exactly the same sample time history is generated when the same process is repeated; by definition a random environment cannot be exactly duplicated. Nevertheless, representative functions of a random process --particularly psd -- can be duplicated with sufficient accuracy by synthesizing signals that are, for practical purposes, sample functions of a given random environment. This repeatability is essential in the generation of test signals to meet required specifications.

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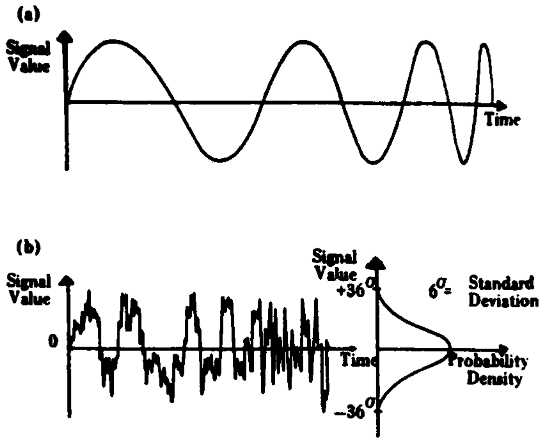

Figure 1. Comparison of Sine-Sweep Signal and Random Signal.
(a) Sine-Sweep Signal
(b) Random Signal and its Probability Density Function

Random testing can more accurately represent vibrations in distribution environments; other characteristics make it superior to sine testing. A sine test is a single-frequency test; thus, only one frequency is applied to a test object at a given instant. As a result, failure modes caused by the simultaneous excitation of two or more modes of vibration cannot be realized by sine testing, at least under steady excitations. In random testing, on the other hand, many frequencies are simultaneously applied to the test object. Conditions are thus more conducive to multiple-mode excitations and associated complex failures.

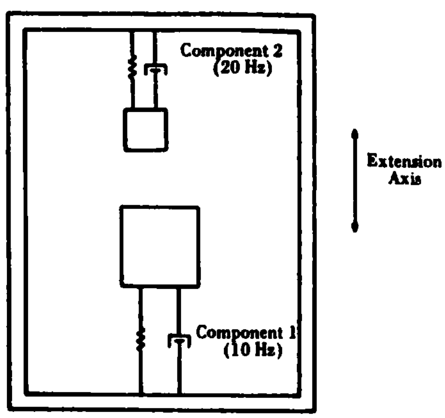

Figure 2 A Device That Can Malfunction under Random Excitations But Not under Sine Excitations

Consider the device shown in Figure 2. Two components with fundamental natural frequencies at 10 Hz and 20 Hz are mounted such that their axes of sensitivity coincide. Suppose a functional failure occurs when the two components come in contact. If the device is excited along the axis of sensitivity by a single sine signal at either 10 Hz or 20 Hz, only one of the two components will resonate and no failure will result. On the other hand, a random excitation, say having a bandwidth of 25 Hz, can excite both components simultaneously at their respective natural frequencies, thereby producing a functional failure.

Whether failure would actually occur depends on the intensity (magnitude) of the excitation as well. In addition, if a single-frequency sine excitation were swept very fast, the resulting transient nature of the excitation would create extraneous frequency components that could lead to functional failure. Furthermore, dynamic characteristics of the mechanical components in a test object can create additional frequency components. Nevertheless, the likelihood of simultaneous motion of intensity sufficient to bring about functional failure is relatively greater when the excitation itself contains components at both natural frequencies. This is generally the case with random excitation. Another advantage of random testing is that because all frequency components of the test environment are simultaneously applied to the test object during testing, test duration is relatively shorter compared to sine testing.

Because many frequency components are excited simultaneously, however, more power is needed for random testing. In addition, shaker control is relatively difficult with random excitations because of the complex test signals. Consequently, random test systems tend to be more costly than their sine counterparts. But the advantages can justify the higher cost. As a result random testing is, in general, more cost effective in the long run.

Efforts have been made to combine the advantages of sine testing and random testing by employing narrow-band random sweeps. Even though this method provides a random environment, modal coupling effects are not simulated unless the modes of the test object are very closely spaced. The reason is that each natural frequency is excited separately just as in the case of sine testing. A preferred method of testing would be to superpose either a sine sweep or a narrow-band random sweep on a wide-band random excitation. Merits and drawbacks of these various test procedures are compared in Table 1.

Table 1. Comparison of Test Types

	SINE TESTING	RANDOM TESTING	NARROW-BAND RANDOM SWEEP	SWEEP ON WIDE-BAND RANDOM
Simultaneous Multimodal (Multiresonant) Excitation?	No	Yes	No	Yes
Test Duration	Long	Short	Long	Moderate
Power Requirements	Low	High	Low	High
Represents a Random Environment?	No	Yes	Yes	Yes
Test System Cost	Low	High	Moderate to High	High
Over-Testing Possibility	High	Low	High	Low

SHAKER CONTROL

When the drive signal is random, shaker control becomes more difficult due to the complex (irregular) nature of the signal. Furthermore, because a random environment cannot be defined by a single time history -- unlike the case of deterministic excitations -- the generation of a drive signal to meet test specifications is more difficult in random testing.

Random-test specification is typically provided using a psd curve. This representation automatically assumes that the random environment is stationary. In other words, no matter what time instant is considered, random characteristics of the signal would remain unchanged. This means, in a weak sense, that the autocorrelation function does not depend on the time origin.

Another essential assumption for practical reasons is the property of ergodicity. Ergodicity assumes that ensemble properties of a random signal are identical to sample properties. In principle, the parameters of a random process are defined by a collection (ensemble) of a large number of sample records of the signal. The ergodic assumption makes possible the determination (computation) of these parameters from one record (sample function). This assumption is essential in dynamic testing because the drive signal is a single sample function of the random process represented by a specified psd. Furthermore, all necessary computations are performed using sample records. Averaging methods are useful in reducing errors introduced by the assumption of ergodicity. It is easy to show that ergodicity implies stationarity, but the converse is not necessarily true.

A random process is associated with a unique probability distribution. One that is widely used, primarily for mathematical simplicity and because of test-system limitations, is the gaussian distribution (normal distribution). The central limit theorem provides physical justification for the gaussian assumption. According to the theorem, a random process that results additively from a large number of independent random factors is gaussian. This is indeed the case in distribution environments. Drive signal generation for random testing typically consists of synthesizing an ergodic (and consequently stationary) and gaussian random signal with a given psd curve.

The word spectrum implies the Fourier spectrum, which expresses magnitude and phase variations of a signal with respect to frequency; that is, it is a representation in the frequency domain. A signal in acceleration (units of acceleration due to gravity g) has a Fourier spectrum magnitude in units, g/Hz. Power spectral density provides the mean-square density of a random signal as a function of frequency; the units are g^2/Hz. The area under a psd curve between two frequency values is equal to the mean-square value of the signal within that frequency interval. The psd function does not contain phase information. This is not a disadvantage because the phase of a random signal varies randomly with respect to frequency.

The word spectrum, in the context of random signals, is often used to imply psd. The amplitude spectrum of a sample function of a random signal can be represented by the square root of the psd, allowing for an appropriate scaling factor. Consequently, after the psd is known, the amplitude spectrum can be determined. By assigning random values for the phase variation, the complex Fourier spectrum of a sample function of random process can be determined. The sample signal itself can be obtained by inverse Fourier transformation. In digital systems, a finite number of psd values at discrete frequency points (spectral lines) are extracted from a specified continuous psd curve. These values are used -- along with discrete phase angles supplied by a random-number-generating routine -- to obtain the discrete Fourier spectrum of a representative random signal. The sample signal is digitally computed by inverse fast Fourier transformation (FFT).

Before the process of synthesizing a shaker drive signal for random testing is explained, it is appropriate to clarify three terms: reference spectrum, drive spectrum, and control spectrum. A random test is specified by a reference spectrum that represents the random excitation required at the test package during testing. Drive spectrum is the spectrum of the random signal that drives the actuators of the shaker and is generated by the controller. If the dynamic behavior of shaker, test fixtures, and test package is completely known, and, if the effects of such electronic hardware as filters, amplifiers, and control circuitry are also known, it is theoretically possible to determine the drive spectrum for a given reference spectrum. If the system is assumed to be linear, the drive spectrum can be determined through the simple transfer function relation shown in Figure 3.

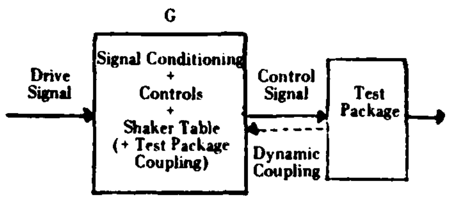

Figure 3. A Block Diagram for Open-Loop Control

However, these ideal conditions do not exist in practice; thus, it is virtually impossible to determine the drive spectrum accurately by this open-loop method. Nevertheless, the older generation of tape-driven analog random control systems has employed this approach. Digital controllers in modern random-test systems employ feedback (closed-loop) control to produce a shaker response that accurately represents the required (reference) spectrum. The spectrum of the actual response of a shaker is called the control spectrum because it is measured by the control sensor (control accelerometer) and compared with the specified reference spectrum in order to correct (or control) the shaker. This nomenclature is further explained in Figure 4, which presents a block diagram for closed-loop control of a shaker system.

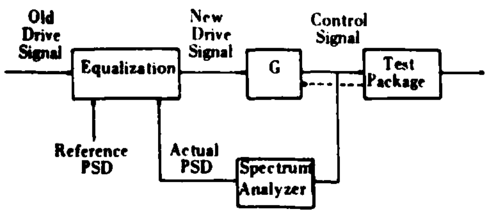

Figure 4. A Block Diagram for Equalization with Closed-Loop Control.

Spectrum Equalization: The process of making a spectrum measured at the shaker table (control spectrum) equal to a specified spectrum (reference spectrum) is termed equalization. It is virtually impossible to realize exact equalization even with most sophisticated control systems. An error band, usually specified in decibels (db) provides the boundaries within which the equalized control spectrum should lie with respect to the reference spectrum.

With the manual equalization prevalent in older random-test facilities the control spectrum generated by an analog narrow-band analyzer is visually compared with the reference spectrum. The drive spectrum is then adjusted by manually changing the gains of individual narrow-band filter-amplifier units in the drive signal synthesizer until an acceptable match is obtained. This slow, trial-and-error procedure is undesirable, particularly because it directly influences the test duration. Specifically, the unregulated excitation applied to the test package during equalization will lead to overtesting. This problem can be alleviated to some extent by performing the equalization at a lower signal level and stepping up the excitation intensity to the full level for actual testing. Due to system nonlinearities, however, the equalized spectrum will change somewhat when the signal level is increased in this manner. Another way to overcome the problem of overtesting is to replace the actual test package with a dummy unit during equalization. A disadvantage it that the control spectrum will be distorted when the dummy unit is replaced by the actual test package for testing.

Newer analog controllers for random testing provided a capability for automatic equalization whereby the drive spectrum could be automatically adjusted using a hardware loop for level control (a compressor loop) in each frequency band. Such system required costly, complex, and bulky analog hardware. Yet the accuracy obtained was often inadequate due to the limitation on the number of available filter (analyzer) bands.

In modern dynamic-test systems automatic digital equalization is available as a standard feature. Equalization time, which is a measure of the effectiveness of a particular controller, is usually specified as the time taken to equalize a 10 db error to within +/- 3 db. An alternate and more stringent definition is the time required to equalize from 30 db to +/- 1db. Equalization time is customarily expressed in terms of control-loop time. One control-loop time is the time required to modify a drive signal after a deviation in the control spectrum has been detected. One method of digital equalization is to compute the Fourier spectrum magnitude of a measured control signal, using FFT, and then update the drive spectrum proportionately with respect to the reference spectrum. Specifically, in terms of Fourier spectral magnitudes;

$$\text{New Drive Spectrum} = \text{Present Drive Spectrum} \times \frac{\text{Reference Spectrum}}{\text{Present Control Spectrum}}$$

This linear equalization algorithm is fast, simple, and effective in most situations. Figure 5 is a typical example showing the reference spectrum, equalized control spectrum, allowed equalization error bounds, and the drive spectrum that produced the equalized control spectrum. The sharp notches in the drive system correspond to resonances in the control system (both mechanical and electrical contributions may be present) that must be clipped (compensated, suppressed) in order to achieve equalization. Note that the low-frequency resonances are primarily from such mechanical components as test table, fixtures, and test package itself. High-frequency resonances can result from the electrical circuitry used in various tasks of signal generation and conditioning, shaker actuation, and control.

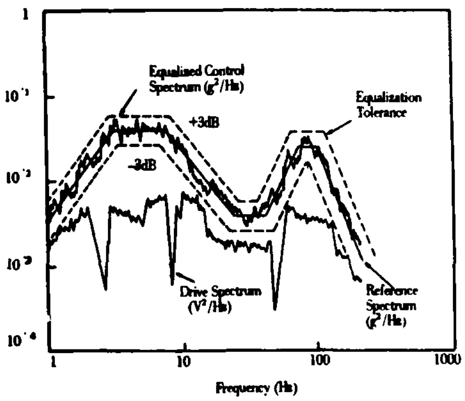

Figure 5. Spectrum Nomenclature.

Drive-Signal Generation: After the spectral magnitude of a drive signal has been determined as outlined above, the next step is to generate a time signal with that spectral magnitude. As mentioned earlier, the random drive signal must be both ergodic (hence stationary) and gaussian.

The first step in signal synthesis is to assign independent and identically distributed random-phase angles to the digitized spectral magnitude (spectral lines) of the drive spectrum. The number of lines chosen is consistent with the FFT algorithm employed and the desired numerical accuracy. The inverse Fourier transform is obtained from the resulting discrete, complex Fourier spectrum. In general, the signal so obtained would not possess ergodicity and gaussianity.

Stationarity can be attained by randomly shifting the signal with respect to time and summing the results. The resulting signal would be weakly ergodic as well. Ergodicity is improved by increasing the duration of the signal. To obtain gaussianity, sufficiently large number of time-shifted signals must be summed as dictated by the central limit theorem. Furthermore, because a gaussian signal is almost always within three times its standard deviation practically (99.7% of the time), gaussianity can be imposed simply by windowing the time-shifted signal. The amplitude of the window function is governed by the required standard deviation of the drive signal. Unwanted frequency components introduced as a result of sharp end transitions in each time-shifted signal component can be suppressed by properly shaping the window. This process introduces a certain degree of non-stationarity into the synthesized signal, particularly if the windowed signal segments are joined end to end to generate the drive signal. A satisfactory way to overcome this problem is to introduce a high overlap from one segment to the next. Because the processing time increases in proportion to the degree of overlap, however, a compromise must be reached.

In summary, for a given drive spectral magnitude the drive signal can be synthesized as follows:

1. Assign independent, identically distributed random phase values to the drive-spectral lines.

2. Perform an inverse Fourier transform of the resulting spectrum using FFT.

3. Generate a set of independent and identically distributed time-shift values.

4. Perform a time-shift of the signal obtained in Step 2 using values from Step 3.

5. Window the time-shifted signals.

6. Join the windowed signals with a fixed overlap.

The resulting digital drive signal is converted into an analog signal using a digital-to-analog converter (DAC) and passed through a low-pass filter to remove any unwanted frequency components before is used to drive the shaker. This procedure is illustrated in Figure 6.

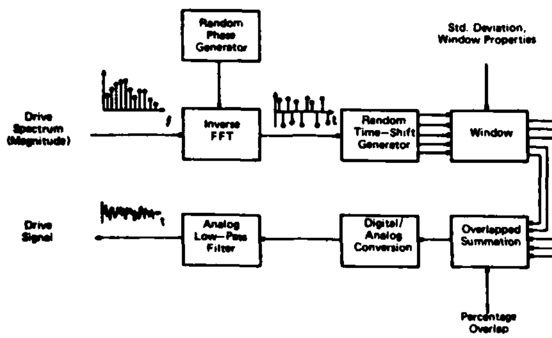

Figure 6. The Synthesis of Random Drive Signal.

DISTRIBUTION SPECTRA

The distribution environment to which a product is subjected depends on several factors: nature and severity of handling prior to and during shipment, mode of transportation (truck, rail, air cargo, ship), geographic factors, environmental conditions, characteristics of the protective packaging used, and dynamic characteristics of the product itself. These factors are complex and essentially random in nature. Laboratory simulation of such an environment is difficult even if a combination of several types of tests -- e.g., vibration, shock, drop, thermal cycling -- is employed. A primary difficulty arises from the requirement that test specifications should be simple yet accurately represent the true environment. The test must also be repeatable to allow standardization of the test procedure and to facilitate evaluation and comparison of test data. Finally, testing must be cost effective.

During transportation a package is subjected to multi degree-of-freedom excitations that can include rectilinear and rotational excitations at more than one location simultaneously. However, test machines are predominantly single-axis devices that generate excitations along a single direction. Thus, any attempt to duplicate a realistic distribution environment in a laboratory setting can prove futile.

An alternative might be to use trial shipments. But, because of the random nature of the distribution environment, many such trials would be necessary before the data would be meaningful. Trial shipments are thus not appealing from a cost-benefit point of view and also because test control and data acquisition would be difficult. Data from trial shipments are extremely useful, however, in developing qualification-test specifications and in improving existing laboratory test procedures.

A more realistic goal of testing would be to duplicate possible failure and malfunction modes without actually reproducing the distribution environment. This is, in fact, the underlying principle of testing for distribution qualification. For instance, sine tests can reproduce some types of failure caused during shipment even though the test signal does not resemble the actual dynamic environment; but random testing is superior.

Test specifications are expressed in terms of distribution spectra in distribution qualification in which random testing is used. Specification development begins with a sufficient collection of realistic data. Sources of data include field measurements during trial shipments, computer simulations (e.g., Monte Carlo simulations), and previous specifications for similar products and environments. For best results all possible modes of transportation, excitation levels, and handling severities should be included. The data, expressed as psd, must be reduced to a common scale -- particularly with respect to the duration of excitation -- for comparison purposes. Scaling can be accomplished by applying a similarity law based on a realistic damage criterion. For example, a similarity law might relate excitation duration and the psd level such that the value of a suitable damage function remains constant. Time-dependent damage criteria are developed primarily on the basis of fatigue-strength characteristics of a test product.

Due to nonlinearities of the environment, spectral characteristics (frequency content) change with the excitation level. If such changes are significant, they should be properly accounted for. The influence of environmental conditions, temperature and humidity for example, must be considered as well. The psd curves conditioned in this manner are plotted on a log-log plane to establish an envelope curve. This curve represents the worst composite environment that is typically expected. The envelope is then fitted with a small number of straight line segments.

At this point the psd curve should be scaled so that the rms value is equal to that before the straight line segments were fitted. The resulting psd curve can be used as the test specification. Test duration can be established from the time-scaling criterion. If the corresponding test duration is excessively long, thereby making the test impractical, the test duration should be shortened by increasing the test level according to a realistic similarity criterion.

Product overtesting can be significant only if one reference spectrum is used to represent all possible distribution environments. Shipping procedures should thus be classified into several groups, depending on the dynamic characteristics of the shipping environment; a representative reference spectrum should be determined for each group. In addition, reference spectra should be modified and classified according to product type if a range of products with significantly varying dynamic characteristics is being qualified. At the testing stage a reference spectrum must be chosen from a spectral data base depending on the product type and applicable shipping procedures. Alternatively, a general composite spectrum can be developed by assigning weights to a chosen set of reference spectra and computing the weighted sum.

Vibration levels in land vehicles and aircraft can range up to several kilohertz (kHz). Ships are known to have lower levels of excitation. In general, the energy content in vibrations experienced during the distribution of computer products is known to remain within 20 Hz. Consequently, test specification spectra (reference spectra) used in distribution qualification are usually limited to this bandwidth. The typical specification curve shown in Figure 7 can be specified simply from the coordinates of the break points of the psd curve. Intermediate values can be determined easily because the break points are joined by straight-line segments on a log-log plane.

The area beneath the psd curve gives the required mean-square value of the test excitation. The square root of this value is the rms value; it is specified along with the psd curve, even though it can be determined directly from the psd curve. An acceptable tolerance band for the control spectrum --usually +/- 3db -- is also specified. Test duration should be supplied with test specification.

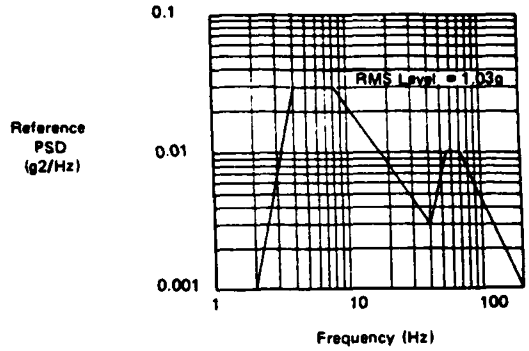

Figure 7. A Reference Spectrum for the Distribution Qualification of personal Computers (Courtesy IBM Corp.)

TEST PROCEDURE

Digital dynamic-test systems are easy to operate. In menu-driven systems, a routine or mode is activated by picking the appropriate item from a menu displayed on the CRT screen. The system then asks for necessary data, and the parameter values are entered into the system. Lower and upper rms limits for test abort levels break point coordinates of the reference spectrum, and test duration are typically supplied by the user. Equalization tolerance bands and accelerometer sensitivities are also entered. More than one test setup can be stored; a number is assigned to each test.

Preprogrammed tests can be modified using a similar procedure in the edit mode. Any preprogrammed test can be carried out simply by entering the required test number. Computed results such as psd curves and transmissibility functions are stored for future evaluation. If desired, these results can be displayed, printed, or plotted with proper annotations and scales while the test is in progress.

Main steps of a typical test procedure are as follows:

1. Carefully examine the test object and record obvious structural defects, abnormalities, and hazardous or unsafe conditions.

2. Perform a functional test (i.e., operate the product) according to specifications and record any malfunctions and safety hazards.

NOTE: The test can be abandoned at this stage if the test object is defective.

3. Mount the test object rigidly on the shaker table, so that the loading points and the excitation axis are consistent with standard shipping conditions and specified test sequence.

4. Perform an exploratory test at half the specified rms level (one-fourth the specified psd level); monitor the response of the test package at critical locations including the control sensor location.

5. Perform the full-level test for the specified duration. Record the response data.

6. Change the orientation in accordance with the specified test sequence and repeat the test.

7. After the test sequence is completed, carefully inspect the test object and record any structural defects, abnormalities, and safety hazards.

8. Conduct a functional test and record any malfunctions, failures, and safety problems.

An exploratory test at a fraction of the specified test level is required for new product models that are being tested for the first time or for older models that have been subjected to major design modifications. Three mutually perpendicular axes are usually tested, including the primary orientation (vertical axis) used for shipping. If product handling during distribution is automated, it is adequate to test only the primary axis.

When multiple tests are required, the test sequence is normally stipulated. If the test sequence is not specified, it can be chosen such that the least-severe orientation (orientation least likely to fail) is tested first. The test is repeated successively for the remaining orientations, ending with the most severe one. The rationale is that with this choice of test sequence, the aging of the most severe direction would be maximized, thereby making the test more reliable and conservative.

The test report should contain the following:

1. Description of the Test Object: serial number, size (dimensions and weight), product function (e.g., system unit, hard file, power supply, printer, key board, monitor, diskette drive), and packaging particulars. Descriptive photos are useful.

2. Test Plan: usually standard and attached to the report as an appendix.

3. Test Setup: test orientations, sensor (accelerometer) locations, details of mounting fixtures, and a brief description of the test apparatus. Photos may be included.

4. Test Procedure: a standard attachment usually given in corporate specifications.

5. Test Results: ambient conditions in the laboratory (e.g., temperature, humidity), pretest observations (e.g., defects, abnormalities, malfunctions), test data (e.g., reference spectrum, equalized control spectrum, drive spectrum, response time histories and corresponding spectra, transmissibility plots, coherence plots) and post-test observations.

6. Comments and Recommendations: general comments regarding the test procedure and test item and recommendations for improving test, product, or packaging.

Names and titles of the personnel who conducted the test should be given in the test report, with appropriate signatures, dates, and location of the test facility.

Tests for distribution qualification can be conducted on both packaged products and those without any protective packaging, even though it is the packaged product that is shipped. The reference spectra used in the two cases are usually not the same, however. The spectrum used for testing a product without protective packaging is generally less severe. Response spectra used for testing an unpackaged product should reflect the excitations experienced by the product during packaging.

COMMERCIAL RANDOM CONTROLLERS

This section contains a summary of a study conducted by the authors to evaluate commercially available digital shaker controllers for random testing. Five digital controllers were chosen and compared (see Tables 2, 3, and 4).

Table 2 presents general capabilities of five systems. Some controllers do not provide sine and shock testing capabilities. This is a significant disadvantage because, for many applications, sine-sweep and sine-dwell tests are specified either as a standard requirement or as an optional test.

Table 2. System Capabilities.

SYSTEM	A	B	C	D	E
Random Test	Yes	Yes	Yes	Yes	Yes
Sine Test	Yes	Yes	Optional	No	Yes
Transient & Shock Tests	Yes	Yes	Optional	No	Yes
Hydraulic Shaker	O.K.	O.K.	O.K.	O.K.	? O.K.
Preprogrammed Test Setups	Max. 63	Max. 25	Max. 99	10 Per Disk	?
Amplitude Scheduling	32 Levels and Durations	Min. Start -25dB, Min Step 0.25 dB, Pick Step Durations	10 Levels over 60 dB	0.5dB Steps Pick No. of Steps and Rate	No
On-Line Reference Modification	Yes	No	Yes	No	No
Use of Measured Spectra as Reference	Yes	Yes (Measurement--Pass Feature	Yes	No	No
Transmissibility	Yes	Measurement Option	Yes	No	Yes
Coherence	Yes	Measurement Option	No	No	Yes
Correlation	Yes	No	No	No	Yes
Shock Response Spectrum	Yes	Yes	Optional	No	Yes
Sine on Random	Yes	Sine Bursts	Optional	No	No
Random on Random	Yes	No	Optional	No	No

The five systems are compatible with hydraulic and electrodynamic shakers. Most systems have the capability to preprogram several test setups when specifications are entered and a number is assigned to each test. Any saved test could be used in subsequent testing. In random testing the full test level is not usually applied to the test object at the start. Fifty percent or less test levels attained by amplitude scheduling are used during spectrum equalization, in exploratory tests, and in aging tests. The test level is changed at specified time intervals without changing the shape of the test spectrum. This feature is also useful in determining the degree of nonlinearity of a test package. The user can modify the reference spectrum while the test is in progress with some control systems. For instance, if the control spectrum matches the reference spectrum over the entire frequency range except at a few locations where equalization error bounds are exceeded, the user can modify the reference spectrum if test specifications will not be affected; the test can then proceed without interruption.

The reference test spectrum is usually entered into a digital controller by specifying the break points of the spectrum. Some systems can specify the reference spectrum using a signal that is either played into the system from a tape or read directly from an accelerometer. The spectrum of the signal is computed using FFT, averaged to improve reliability, and stored for future use as a reference spectrum. Actual field excitations can thus be used to specify tests with the advantage of improved frequency resolution. The capability of using a measured reference spectrum is available in a few systems either as a standard feature or as an option. Test level can be adjusted depending on the test duration.

Readings from the control accelerometer and other accelerometers mounted at critical locations on the test object are useful for monitoring the progress of the test; for example, in comparing an actual control spectrum with the reference spectrum or for future evaluation of the test. The capability to compute transmissibility curves, coherence functions, autocorrelations, and cross correlations is available with some digital controllers. Transmissibility (strictly, motion transmissibilty) is the magnitude of the transfer function, motion output/motion input. A transmissibilty curve provides resonant frequencies and modal damping ratios of the tested product. The coherence function indicates the degree of purity of input and output measurements and is expressed in the frequency domain. Autocorrelation measures the interdependence of a signal at two time points. Cross correlation measures the interdependence of two signals in the time domain.

Shock testing is often specified using a shock response spectrum (SRS); the peak response of a single-degree-of-freedom system (simple oscillator) excited by the specified shock, is expressed as a function of the natural frequency of the system. Some systems have this capability. Several systems also provide a mixed-mode testing capability; for example, sweeping with either a sine excitation or a narrow-band random excitation back and forth over a specified frequency interval while the test object is excited by a fixed wide-band random signal.

Table 3 summarized important hardware characteristics of the five systems. The maximum number of break points on the reference spectrum that can be specified indicates the level of accuracy achievable in entering complex test spectra. Accuracy is improved if the break points are joined on the log-log plane and not on the linear plane. The available number of spectral lines is governed by the number of discrete frequency points computed in Fourier analysis. The total number of frequency points computed by the Radix-2 FFT algorithm can be expressed as a positive integer power of two (128, 256, 1024, 2048). Because approximately 20% of the computed values -- those at the high-frequency end -- might be significantly distorted due to aliasing error, the number of useful spectral lines is often rounded downward to a multiple of ten.

Aliasing distortion is caused by the periodicity of digitally computed spectra; high-frequency components beyond the upper frequency limit (also known as cut-off frequency, Nyquist frequency, or computational bandwidth) of the digital spectrum fold over to the low-frequency side. Aliasing could be eliminated if the signal could be filtered to remove the high-frequency spectrum beyond the Nyquist frequency prior to Fourier computations. But such filtering is virtually impossible to achieve, and some aliasing distortion is always present in a digitally computed spectrum.

Frequency resolution is the smallest detectable frequency change. It is measured in digital spectral analysis by the spacing of the spectral lines. For a given bandwidth, therefore, spectral resolution improves with the number of spectral lines.

Table 3. System Characteristics and Hardware

SYSTEM	A	B	C	D	E
Reference Spectrum Break Points	40	32	60	? 10	45
Spectrum Resolution (Number of Spectral Lines)	Pick 100, 200, 400, 600, 800 Lines	Pick 64, 128, 256, 512 Lines (Optional 1024 Lines	Pick 100, 200, 400 800 Lines	200 Lines 10 Hz Spacing	Pick Any Number: 10-1000 Lines (Optional 2048 Lines
Nature or Random Drive Signal	?	Gaussian, Periodic Pseudo-Random	Gaussian	Gaussian	Pseudo-Random
Measured Signal Averaging	RMS, Peak-Hold	Arithmetic Peak-Hold	True Power	Peak Pick	No
Operator Interface	Key Board, Menu-Driven RS 232	Key Board, Push Button, Dialog, Set-up	Key Board, Push Button, Dialog, Menu-Driven	Key Board, 10 Soft Keys, Dialog	Key Board
Output Devices	CRT Screen, Hard Copy, Video Print, Digital Plot	Stndrd. or Graphics Terminal, X-Y Record Printer, Digital Plot	Graphics Terminal, Video Hard Copier, Digital Plotter, X-Y Record	Like IBM PC; Monochrome (9"), Epson Printer	Graphics Terminal Printer, Hard Copy X-Y Plotter
Memory	128K	64K	128K	64K	32K Stndrd. 64K Option
Mass Storage	Floppy Drive 0.5M, Winchester Drive 10M	One Floppy Drive, 256K	Hard + Floppy 8M, 20M, 30M	Two Floppy Drives 360K Each	Two Floppy Drives 256K Each
Number of Measurements (Cntrl. Input) Channels	2 Stndrd. 16 Option.	2 Stndrd. 4 Option. Multiplexer Optional	1 Stndrd. 16, 31 Optional	1 Stndrd. 4 Option.	?
Number of Controller Output Channels	One	One	One	One	One

Because the amplitude of a Fourier spectrum is assumed reproducible in a test excitation, the test signal is not random in the true sense. Note, however, that random phase-angle values are assigned to the spectral magnitudes, so that the signal is close to random (pseudo-random). Furthermore, amplitude windowing and time-shift averaging methods are employed to make the synthesized excitation signal almost stationary and gaussian in accordance with common test specifications. Periodic pseudo-random signals are not gaussian. They are relatively easy to generate, however, and the shaker can be driven in a more orderly fashion with these signals. Matching a complex reference spectrum to a periodic pseudo-random drive signal is generally more difficult.

More than one accelerometer signal may be available from response measurement channels known as control channels. But the controller compares only one feedback signal with the required reference spectrum in order to correct the drive signal supplied to the controller output channel. When several control accelerometers are employed, averaging is used to combine important characteristics in the accelerometer signals into a single control signal. Available methods for averaging include peak-hold or peak-pick. Either the highest peaks are retained or arithmetic averaging rms or power averaging is used. In the latter signal power is determined at each time instant either by computation or by direct measurement and then averaged. The averaging method used should be based on the most important characteristics of the excitation environment in a given test. Peak-hold is probably the least stable method from the shaker control point of view but is favored when expected failure modes are attributed primarily to peak values of stresses and motions.

Table 4 compares system specifications. Some of these parameters are important in establishing the compatibility of a controller with a particular shaker and response sensor/transducer (accelerometer/charge amplifier) system. These specifications are particularly useful when an existing shaker is retrofitted with a digital controller.

Other parameters quantify system performance. Many of the terms are either self-explanatory or have been explained in previous sections. Digital resolution, which refers to the word size of digitized signals, limits the range of the signal level. Specifically, with an n-bit word the signal magnitude can range from 2^0 to 2^n (or from -2^{n-1} to $+2^{n-1}$). The corresponding magnitude ratio is 2^n, which can be expressed in decibels as $20 \log_{10} (2^n)$. This value is termed dynamic range.

Control accuracy is governed by the degree of spectral matching between the control spectrum and reference spectrum that can be achieved, particularly in the neighborhood of peaks (resonances). For systems that provide a sweep-testing capability -- for example in mix-mode testing -- sweep rate is an important parameter. It gives the rate of frequency change during a sweep. Sweep rate can be specified either in a log scale (octaves per minute or decades per minute) or in a linear scale (hertz per minute). Maximum sweep rate is limited by the speed of controller and mechanical dynamic characteristics of the shaker system. Acceleration level of 0.5g and sweep rate of 0.3 decades/minute are commonly used in sine testing for distribution qualification of microcomputers.

Table 4. System Specifications

SYSTEM	A	B	C	D	E
Accelerometer Signal (Cntrlr. Input)	+/-125 mV to +/-8V Full Scale	10mV RMS to +/- 8V Max. Typically > 500mV RMS	Max 10V Peak, 3.5V RMS ?	1 to 1000 mV/g User Picked	?
Controller Output Signal	2.4V RMS (Random), 20V P-P (Sine & Shock)	20V P-P Max. 50 mA Max.	20V P-P Max.	10V Peak, 3V RMS	?
Input Frequency Ranges	Random: DC to 200Hz, 500Hz, 1kHz, 2kHz 3kHz, 4kHz 8kHz. Sine: 1Hz-8kHz Shock: 10Hz-125Hz 312Hz,... 5kHz	Seven Ranges Max Freq. = 50Hz-5kHz Min. Freq./#Lines	100Hz, 500Hz, 1kHz, 2kHz, 4kHz 5kHz 10kHz	10Hz to 2000Hz	10Hz to 5000Hz
Control Loop Time	2.1 Sec. (2kHz, 200 Lines)	0.3S-64 Lines 0.9S -256 ,, 3S-1024 ,, (2kHz)	4S-100 Lines 8S-200 ,, (2kHz)	2 Sec.	2.5 Sec For 256 Lines at 2kHz
Equalization Time for 10dB Range	Within +/- 3dB in Two Loops	2 or 3 loops ?	Within +/- 1dB in One Loop	Within +/- 1dB in 6 Sec.	?
Solution	12 Bits	12 Bits			12 Bits
Dynamic Range	65dB	65dB	72dB	60dB	
Control Accuracy	+/-1dB at Q=30 +/-2dB at Q=50 (100Hz Resonance, at 1Oct/Min.	+/-1dB (at 90% Confidence	+/-1dB Over 72dB	+/-1dB	+/-1dB (at 95% Confidence
Sine Sweep Rate	O.K.	0.1-100 Oct/Min (log) 1Hz-100kHz/Min (Linear)	0.1-100 Oct/Min Max. 0.1Hz -6kHz/Min	N/A	0.001-10 Oct/Min 1-6000Hz/Min

Note that systems A, B, and C are competitive with respect to their capabilities, characteristics, and specifications. Any one is adequate for the current application.

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The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four reviews each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the **DIGEST** reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

EARTH PENETRATION BY SOLID IMPACTORS

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Abstract. Prediction of earth penetration depth of solid impactors using analytical, semi-analytical, and empirical techniques is reviewed and summarized. A new simple formula for predicting penetration depth in single-layered cohesive soils is proposed. The new formula is compared with the Sandia and Kar formulas.

The need for improving the effectiveness and accuracy of earth penetration weapons as well as achievement of the maximum possible safety of shelters were some of the main reasons for research in the area of earth penetration. Various uses and applications of impactors (not necessarily weapons) were also motivations for study. Remote sensing surveys, determinations of sea-ice thickness and water depths, and subsurface profile investigations for delineating discontinuities in soil properties are some of the uses of earth impactors.

The analytical study of earth penetration requires a clear understanding of the penetration mechanism and adequate evaluation of the interaction parameters at the impactor-target interface. Techniques range from semi-analytical to purely theoretical and comprise early simple mathematical formulations of Newton's equation of motion as well as recent numerical solutions based on finite element-finite difference-coupled computer programs. In subsequent sections these techniques as well as empirical techniques are summarized and reviewed.

SEMI-ANALYTICAL TECHNIQUES

Newton's second law of motion relates the resisting force to the product of mass and acceleration and is the basis for most semi-analytical techniques. Such formulation leads to the following relationship:

$$Mg - F = Ma_p \tag{1}$$

M is the mass impactor, g is acceleration, a_p is acceleration of the impactor, and F is the target resistance force that opposes penetration. The weight of the impactor Mg is usually small compared with the resisting force F; thus, the equation can be rewritten as follows:

$$-M \frac{d^2z}{dt^2} = F \tag{2}$$

where z = depth of penetration at time t

d^2z/dt^2 = acceleration of impactor

A generalized resistance function F in the following form has been assumed by a number of investigators:

$$F = A_1 + B_1\frac{dz}{dt} + C_1z + C_2z\frac{dz}{dt} + E_1\left(\frac{dz}{dt}\right)^2 \tag{3}$$

Substitute equation (3) in equation (2). Note that, for a given impactor, the mass M is constant; the following equation is obtained:

$$-M\, d^2z/dt^2 = A_1 + B_1\, dz/dt + C_1z + C_2z\, dz/dt + E_1\, (dz/dt)^2 \tag{4}$$

The constant A_1 is considered a contribution to resistance resulting from the bond strength of the target material. The constant B_1 represents viscous resistance of the target material. The constant C_1 represents resistance to penetration due to gravitational effects. The constant C_2 represents the interaction between gravitational effects and viscous resistance. E_1 represents that contribution to total resistance arising form velocity.

After the resistance function has been postulated, equation (4) can be integrated with the proper initial and boundary conditions as follows:

when t = 0, dz/dt = v and z = 0
when $z = X_p$, dz/dt = 0.

V is the impact velocity; X_p is the penetration depth.

Equation (4) is the basic relationship from which a number of investigators have derived their equations. These equations are tabulated in

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Table 1. Robins and Euler [10,2] assumed that all constants in the equation produce negligible effect on the depth of penetration except A_1. They integrated the resulting equation using the above-mentioned initial and boundary conditions and obtained the first equation in Table 1.

Table 1. Semi-Analytical Earth Penetration Formulas.

Name	Formula	Remarks
Robins-Euler	$X_p = \frac{V^2}{2A_1}$	A_1 = constant indicating the contribution of resistance resulting from target bond strength; obtained from experimental data
Poncelet	$X_p = \frac{1}{2E_1} \ln (1 + \frac{E_1}{A_1} V^2)$	E_1 = constant representing contribution of resistance arising from velocity; obtained from penetration test
Petry	$X_p = \frac{W}{A_1} K_s \log_{10} (1 + \frac{V^2}{215000})$	K_s = soil penetration constant; obtained from experiment
Resal	$X_p = \frac{1}{E_1} \ln (1 + \frac{E_1}{B_1})$	B_1 = constant depending on velocity; represents viscous resistance of target material
Allen	$X_p = \frac{M(V-C_2)}{6\rho\nu(\pi A_1)^{.5} N_1}$	= target mass density = target kinematic viscosity N_1 = shape factor C_2 = constant representing resistance to penetration due to gravitational effects

Similarly, Poncelet [8] assumed that the constants B_1, C_1, and C_2 produce no effect on the depth of penetration and found the second equation in Table 1. Petry's equation [7] is a simplified form of Poncelet's equation except that the factor E_1/A_1 is assumed to be a unique constant equal to $1/215 \times 10^3$.

Resal [9] assumed that the constants A_1, C_1 and C_2 have no significant effect on penetration depth and obtained the fourth equation in Table 1. Allen [1] assumed that the impactor behaves as a rigid body and that the target material is a viscoplastic solid and found the last equation in Table 1.

These formulas have been derived mathematically, but the coefficients must be determined from actual penetration test data. Consequently, a great deal of empiricism is necessary when these equations are used to predict depth of penetration. Further, extrapolation to conditions beyond the range of experimental data may not be valid.

ANALYTICAL TECHNIQUES

The Cavity Expansion Theory. The cavity expansion theory [3,4] assumes that the resistance to penetration is contributed by two separate sources. One is shear resistance, which is the resistance of target material to deform under shear stresses. The second is dynamic resistance, which results from inertial effects of projectile movement in the target material. For penetration greater than one projectile radius into a homogeneous target material, the cavity expansion theory expresses the depth of penetration by the complex equation given in Table 2.

Table 2. The Cavity Expansion Formula.

$$X_p = \left(\frac{3W}{4Ag\rho_p\phi_2} + \frac{\phi_1 R}{2\phi_2}\right) \ln \left(1 + \frac{2\phi_2\rho_p V_s^2}{3\phi_3}\right)$$

Y	=	yield strength of soil, lbs/ft^2
E_t	=	strain hardening modulus of soil, lbs/ft^2
ρ	=	initial mass density, slugs/ft^3
ρ_p	=	locked plastic mass density, slugs/ft^3
ϵ_i	=	volumetric strain in the elastic region of the pressure-volumetric strain curve
ϵ_p	=	volumetric strain in the plastic region of the pressure-volumetric strain curve
A	=	cross-sectional area of projectile, ft^2
R	=	radius of projectile, ft
V_s	=	$(V^2 - \frac{4.7\pi R^3 gY}{W})^{0.5}$
ϕ_1	=	$1 - \delta^{1/3}$
ϕ_2	=	$3/2 - (1 + \alpha_p)\,\delta^{1/3} + 1/2\,\delta^{4/3}$
ϕ_3	=	$4/9\,E\,[1-e^{-3\beta}] - 2/3 \ln\delta + 2/27\pi^2 E_t - 4/9 E_t \eta$
δ	=	$1 - \rho_o e^{-3\beta}/\rho_p$
α_p	=	$1 - \rho_o/\rho_p$
η	=	$\sum_1^n \frac{\delta_n}{n^2}$
β	=	$\frac{Y}{2E} - \frac{\epsilon_i}{3}$
ρ_p	=	$\rho_o e^{\epsilon_p}$

AVCO Corporation Differential Area Force Law. A common characteristic of penetration techniques, both semi-analytical and analytical, is their inability to treat oblique impact. AVCO Corporation [5] postulated that normal and tangential stresses acting on a differential area of an impactor during oblique impact are functions of the velocity vector of the projectile during its subsurface trajectory. Various contributions of total resistance to penetration of the AVCO Corporation differential force law include compressibility effects, surface effects, structural resistance to penetration, and fluid-flow effects. These factors do not necessarily contribute simultaneously toward total resistance in any given penetration problem. The components of the differential force are defined in Table 3.

Table 3. AVCO Corporation Differential Force Law.

The AVCO Formula:

$$\left[\frac{dF}{dA}\right]_n = \eta + 1/2\rho V^2 C_n \sin^2 \zeta + \rho c V e^{-\alpha t}(t-\tau) + \text{surface effects}$$

$$\left[\frac{dF}{dA}\right]_\tau = \eta f_c + 1/2\rho V^2 C_\tau \sin \zeta \cos \zeta + f_c \rho c V e^{-\alpha t} \mu(t-\tau) + \text{surface effects}$$

$\left[\frac{dF}{dA}\right]_n$	=	normal component of stress on differential area
$\left[\frac{dF}{dA}\right]^\tau$	=	tangential component of stress on differential area
η	=	basic structural resistance to penetration (for normal impact where no tangential stresses occur, it represents the static force per unit area)
ρ	=	mass density of target material
V	=	normal equivalent flow coefficient (an empirical constant that is a function of velocity and nose shape
ζ	=	local incidence angle (obliquity with normal=$\pi-\zeta$)
c	=	seismic p-wave velocity of target material
α	=	exponential decay factor
$\mu(t-\tau)$	=	mathematical control on the timing of compressibility effects
f_c	=	coefficient of friction
C_τ	=	shear equivalent flow coefficient (interface friction between projectile & target material)

Integrating these two differential equations furnishes the resultant force acting on the impactor. This resultant force, which may act eccentrically with respect to the center of gravity of the impactor, establishes the subsurface trajectory of the impactor in one-, two-, or three-dimensional coordinates. This approach suffers from the fact that the coefficients are empirically determined and are not obtained from the physical properties of the target material.

Table 4. Experimental Results of Single-Layer Earth Penetration.

D	W	K	Q	V	X	S
8.5	300.	1.32	76	307	4.3	2.1
8.5	300.	1.32	76	350	4.7	1.9
8.5	300.	1.11	76	265	3.3	2.5
8.5	300.	1.32	76	265	3.6	2.2
8.5	300.	1.32	76	257	3.5	2.4
8.5	300.	1.32	76	262	3.7	2.3
8.5	300.	1.32	76	250	3.7	2.6
8.5	352.	1.32	76	211	3.1	2.7
8.5	454.	1.32	76	197	3.4	3.0
8.5	300.	1.32	76	350	5.0	2.0
8.5	300.	1.32	76	258	4.0	2.6
8.5	300.	1.32	76	257	3.8	2.5
1.56	7.8	.82	59	110	.78	4.1
1.56	7.3	1.11	29	115	.75	2.8
1.56	7.4	1.32	29	110	.84	2.8
1.56	7.3	.82	29	190	.94	2.0
1.56	7.3	.82	29	193	.96	2.0
1.56	14.7	.82	29	115	.85	3.0
1.56	29.9	.82	29	99	1.10	3.6
1.56	7.8	.82	26	112	.78	4.0
1.56	7.8	1.32	26	115	.97	2.9
1.56	7.8	.82	26	112	.78	4.0
1.56	7.8	1.11	26	113	.88	3.2
1.56	7.8	1.08	26	110	.88	3.5
1.56	14.7	.82	26	110	1.17	4.5
1.56	29.9	.82	26	100	1.47	4.7
1.56	14.7	.82	26	117	1.29	4.4
1.56	7.3	.82	26	117	.84	4.1
1.56	7.3	.82	26	155	.98	2.9
1.56	7.3	.82	26	198	1.23	2.5
2.18	15.3	.82	26	101	.78	4.8
3.06	31.0	.82	26	116	1.02	4.8
1.56	7.3	.82	10	115	1.83	9.1
1.56	7.8	.82	10	67	.98	12.9
4.4	222.	1.00	139	111	2.7	5.9
4.4	222.	.82	139	113	2.0	5.3
4.4	222.	.82	139	169	4.0	5.2
4.4	222.	1.00	139	163	4.6	5.2
4.4	222.	1.11	139	110	3.1	6.1
4.4	222.	.56	139	172	2.8	5.4
4.4	222.	1.11	139	168	5.3	5.1
4.4	222.	.82	139	166	4.3	5.9
4.4	222.	1.00	139	201	6.5	5.3
3.1	216.	1.11	139	112	3.8	5.4
4.4	222.	.82	139	175	4.3	5.4
3.1	216.	1.11	139	140	5.2	5.2
5.4	339	1.11	139	138	4.3	5.9
4.4	222.	.82	139	170	4.0	5.3
4.4	222.	.82	111	213	6.1	5.5
5.4	222.	.82	111.	210	6.8	5.7
1.56	7.3	.82	94	115	1.03	5.2
4.4	222.	.82	97	172	3.9	5.0
4.4	222.	.82	97	170	4.1	5.4

NUMERICAL TECHNIQUES

Finite differences, finite elements, or both have been used to obtain numerical solutions to the penetration prediction problem. Application of numerical techniques requires complex constitutive relationships of the target material [11,13]. These numerical techniques provide a rational way of evaluating the response of an impactor during its subsurface trajectory. However, most investigators in this area agree that such computational techniques are not warranted for predicting the maximum depth of penetration. Empirical formulas are as accurate as the more sophisticated numerical solutions, which are also very costly from the computational point of view.

EMPIRICAL TECHNIQUES

Lack of sufficient understanding of the penetration mechanism and the complexities involved in assessing the physical properties of target materials under dynamic conditions have led a number of investigators to resort to empirical techniques for penetration prediction. These techniques are summarized in this section.

The Sandia Empirical Technique. Sandia Laboratories gathered a large inventory of full-scale projectile penetration data between 1961 and 1972. The Sandia empirical technique [14] assumes that, for normal impact, penetration depth can be expressed as a function of projectile *nose shape*, *cross-sectional area*, *weight*, impact velocity, and target material penetrability. The first four parameters depend on the characteristics of the projectile. The fifth describes the influence of material properties on penetrability.

After studying more than 200 full-scale penetration tests and the effect of each factor on the depth of penetration, Sandia Laboratories developed the following two formulas [14]:

$$X_p = 0.53\ SK(W/A)^{0.5}\ \ln\ (1+2V^2/10^5)$$

$$V \leq 200 \text{ ft/sec.} \tag{5}$$

$$X_p = 0.0031\ SK(W/A)^{0.5}\ (V-100)$$

$$V \geq 200 \text{ ft/sec.}$$

W is projectile weight, V is impact velocity, and S is penetrability index. K is the nose shape factor; it is equal to .56 for a flat nose and 1.33 for a conic nose.

The two equations are applicable only when the depth of penetration is equal to or greater than three projectile diameters plus one nose length. For shallower penetrations, surface effects appear to dominate the penetration phenomenon, and the penetration mechanism presents complexities that are not fully understood. The penetrability index S is obtained either from a full-scale penetration test at the site or from previous experience on a similar site. There is thus no correlation between the penetrability index S and any of the physical properties of the target material. Therefore, the penetrability index S for a new region where no previous experience is available could not be evaluated unless a full-scale penetration test were conducted. The Sandia formula is considered one of the most simple and accurate of the empirical techniques. The way in which the penetrability index is introduced is a major shortcoming of the formula, however.

Kar Formula. In 1977 Kar [6] proposed an empirical formula for the determination of the depth of projectile penetration into uniform or layered-earth media. The soil can vary from soft clay to competent rock. The formula is as follows:

$$G(X_p/D) = \frac{\alpha}{Q^{0.5}}\ K\ \left(\frac{E}{E_s}\right)^{1.25} \frac{W}{D_0^{1.66} D_e^{0.65}} \left(\frac{V}{1000}\right)^{1.25} \tag{6}$$

where

$$G(X_p/D) = \begin{cases} (X_p/2D)^2 & \text{for } X_p \leqslant 2.0 \\ (X_p/D)^{-1} & \text{for } X_p \geqslant 2.0 \end{cases}$$

The factor K is a projectile shape factor given by the following equation:

$$K = 0.72 + \frac{(CRH)^{2.72}}{1000} \leqslant 1.45 \tag{7}$$

CRH is the caliber radius head and equals the radius of curvature of the nose shape divided by the diameter of the projectile. For hollow circular impactors, the K value is obtained by the following equation:

$$K = 0.72 + 0.036\ \left[\ \left(\frac{D_0}{D_e}\right)^2 - 1\ \right] \leqslant 1.17 \tag{8}$$

D_0 is the outer diameter of the impactor, and D_e is the equivalent diameter. A method for determination of D_e is available [6]. In equation (6) Q is the unconfined compressive strength of the target material, E is the elastic modulus of projectile material in psi, and E_s is the elastic modulus of D6A-C steel used in the tests, equal to 30 x 10^6 psi. When the different quantities in the equation are in foot-pound-second units, equals 123.36.

New Earth Penetration Formula. The authors of this review have presented a simple formula for estimating the soil-penetration depth using the results of tests conducted by Sandia Laboratories [12], summarized in Table 4. A dimensionless penetrability factor P is defined as follows:

$$P = \frac{KMV^2}{QD^3} \tag{9}$$

K is the impactor nose shape factor, M is the impactor mass, V is the impactor velocity, D is the impactor diameter, and Q is the unconfined strength of target material. A plot of the penetrability factor P vs penetration depth X divided by impactor diameter D is a linear relationship. A least squares technique was used to obtain the relationship shown in Figure 1 and Figure 2.

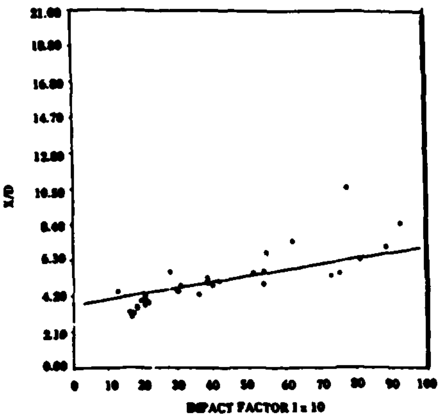

Figure 1. Penetrability Factor P vs Penetration Ratio X/D for $10 \leq Q \leq 80.0$ psi.

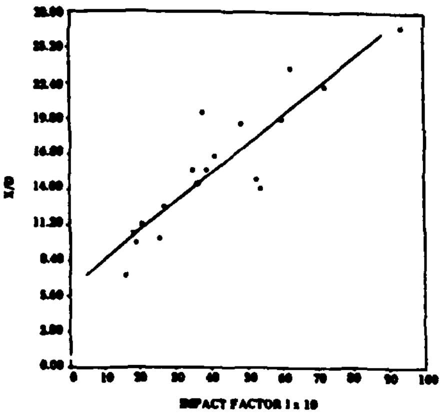

Figure 2. Penetrability Factor P vs Penetration Ratio X/D for $140 \geq Q \geq 80.0$ psi.

The following formulas for predicting penetration depth have been found.

$$X_p = 3.6804 + 0.00758\ P$$

$$10.0 \leq Q \leq 80.0 \text{ psi} \tag{10}$$

$$X_p = 4.6669 + 0.03788\ P$$

$$80.0 \leq Q \leq 140.0 \text{ psi} \tag{11}$$

These formulas are dimensionless and easy to use. A simple strength parameter such as unconfined strength Q is the only quantity that has to be evaluated to compute the penetration depth X_p. The formula can be used for any single-layer soil penetration. Such a situation typically exists for the soil that covers shelters or any other underground structures. The following ranges of applicability are the limits of the test data used in developing the earth penetration equations [11,12].

$1.56 \leq D \leq 8.5$ in
$7.3 \leq W \leq 454$ lb
$10.0 \leq Q \leq 140.0$ psi
$60.0 \leq V \leq 350.0$ ft/sec.
$0.75 \leq X \leq 7.0$ ft

Table 5 summarizes the empirical formulas as well as some other empirical formulas developed in the 1960s.

COMPARISON OF EARTH PENETRATION FORMULAS

Until 1976, when Triandafilidis compared penetration techniques [12], the various earth penetration formulas had not been subjected to comprehensive comparisons against actual field penetration data. The Sandia empirical prediction formula is an exception because its development was based on extensive field penetration measurements and tests. Triandafilidis [12] concluded that the simple Sandia empirical formula yields results within the same margin of accuracy as the more elaborate analytical and numerical techniques. These techniques include the cavity expansion theory and the AVCO Corp. differential force law formula. Recent empirical formulas of Sandia and Kar are compared with the new formula below.

Figure 3 shows a scatter diagram for Sandia, Kar, and the new formula in which the predicted penetration depth X_p divided by the observed penetration depth X is plotted vs penetration ratio (observed depth/impactor diameter). The Sandia formula fits the data better than the others. The standard deviation for the new formula was found to be 0.42. Therefore, it is suggested that one standard deviation be added to the penetration depth computed by the new formula as a factor of safety.

Name and Formula	Remarks
Hermann et al. (1963) $X_p = 0.36\, D \left(\frac{\rho_p}{\rho_t}\right)0.67 \left(\frac{V^2}{H_t}\right)0.33$	ρ_p = projectile mass density ρ_t = target mass density H_t = coefficient obtained from experimental data; depends on target material
Kornhauser (1964) $X_p = 0.06 \frac{W}{\pi D^2 \gamma_p}$	γ_p = projectile mass density
Rohani (1965) $X_p = mDV^c$	m = dimensional coefficient c = positive integer dependent on target material; varies between 0.5-0.7 $V \leq 700$ ft/sec
Sandia (1972) $X_p = 0.53\, SK(W/A)^{0.5} \ln(1+2V^2/10^5)$ $V \leq 200$ ft/sec. $X_p = 0.0031\, SK(W/A)^{0.5}(V-100)$ $V \geq 200$ ft/sec.	S = penetrability index K = impactor nose shape factor
Kar (1977) $G(Xp/D) = \frac{\alpha}{Q^{0.5}} K \left(\frac{E}{E_s}\right)1.25 \frac{W}{D_0^{1.66} D_e^{0.65}} \left(\frac{V}{1000}\right)1.25$ where $G(X_p/D)^{-1} = \begin{cases} X_p/2D & \text{For } X_p \leq 2.0 \\ (X_p/D)^{-1} & \text{For } X_p > 2.0 \end{cases}$ $K = 0.72 + \frac{(CRH)^{2.72}}{1000} \leq 1.45$	Q = target unconfined strength psi E = projectile elastic modulus E_s = 30000000 psi α = 123.36
The New Formula (1984) $X_p = 3.6804 + 0.00758\, P$ $10.0 \leq Q \leq 80.0$ psi $X_p = 4.6669 + 0.03788\, P$ $80.0 \leq Q \leq 140.0$ psi P = penetrability factor $= \frac{KMV^2}{QD^3}$	

Table 5. Empirical Earth Penetration Formulas

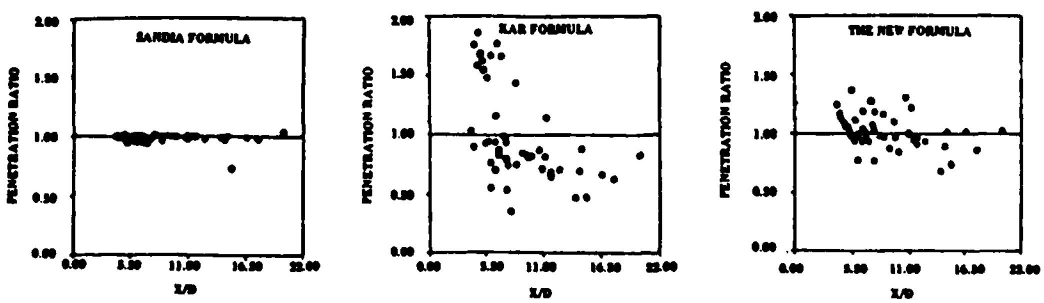

Figure 3. Scatter Diagrams of Soil Penetration by Sandia, Kar, and the New Formula.

Figure 4 shows a comparison among Sandia, Kar, and the new formula for a typical impactor of weight 300 lb, diameter 8.5 in, nose shape factor 1.32, and target unconfined strength of 76.0 psi. The new formula is closer to the Sandia formula than the Kar formula is to the Sandia formula.

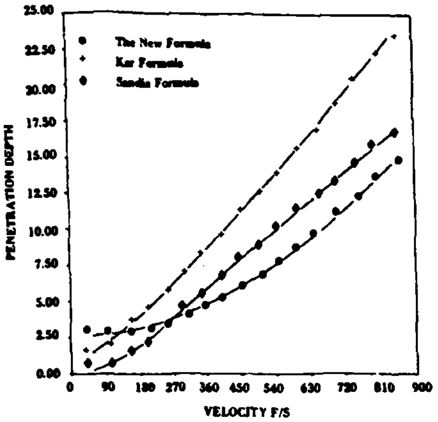

Figure 4. A Comparison of Sandia, Kar, and the New Formula.

CONCLUSIONS

The Sandia empirical formula provides a reasonably approximate method for predicting penetration depth in soil. However, the inclusion of the penetrability index makes it difficult to use in regions with different soils. The new formula proposed in this paper is somewhat less accurate, but it avoids use of the penetrability index S, which must be obtained either from a full-scale penetration test or from previous experience. The soil penetration formula presented in this paper is particularly useful in regions where extensive geotechnical information is not readily available. It can also be used in preliminary investigations and design where extensive field experimentations may not be feasible. Finally, the available experimental data base for soil penetration needs to be extended to include such parameters as soil type.

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APPENDIX — NOTATION

The following symbols are used in this paper:

a_p = acceleration of impactor

A = cross-sectional area of impactor

c = positive exponent that depends on target material properties in Rohani formula

D = diameter of the impactor, in

D_e = equivalent diameter of impactor, in

D_0 = outside diameter of impactor, in

F = target resistance force opposing penetration

g = gravity acceleration, ft/sec^2

H_t = coefficient that depends on target material in Hermann formula

K = nose shape factor of impactor

K_s = soil penetration constant obtained from experiments in Petry formula

m = dimensional coefficient in Rohani formula

M = mass of impactor, lb

P = penetrability factor

$= \frac{KMV^2}{QD^3}$

Q = unconfined compressive strength of soil material

S = penetrability index in Sandia formula

V = velocity of impactor, ft/sec

W = weight of impactor, lb

X = observed earth penetration depth, in

X_p = calculated earth penetration depth, in

BOOK REVIEWS

BOUNDARY ELEMENT TECHNIQUES

C.A. Brebbia, J.C.F. Telles, L.C. Wrobel
Springer-Verlag, New York & Berlin
1984, 464 pp, $72.00

The boundary element method (BEM) is a useful tool to the designer, engineer, analyst, and physicist. As stated by the authors, "The purpose of this book is to present a comprehensive and up-to-date treatment of BEM ... to present the techniques as an outgrowth of FEM in a way that is simple for engineers to understand." The authors have compiled a book on BEM that is useful to the engineer. The bibliography and references at the end of each chapter are comprehensive.

The book consists of 14 chapters and two excellent appendices on numerical integration formulas and semi-infinite fundamental solutions. Chapter 1 introduces the topic of approximate methods. Weighted residual methods includes the collocation method, Galerkin method, and weak formulation methods.

Chapter 2 discusses potential theory, including direct and indirect formulation of the elements, the Poisson equation, and subregions. Additional topics are the axisymmetric problem with arbitrary boundaries and three-dimensional problems. Chapter 3 considers the interpolation functions required to reduce the integral equation so that the methods employed in algebraic equations can be used. Linear elements for two-dimensional problems and boundary elements for two- and three-dimensional problems are covered, including quadrilateral elements (simple and higher order), Lagrangian elements (simple triangular and higher order triangular), and three-dimensional cellular elements (tetrahedron and cube).

The subject of Chapter 4 is diffusion. Included are the Laplace transform, boundary element-finite difference method, time-dimensional and two-dimensional problems (constant, linear, quadratic time interpolation), and axisymmetric problems and nonlinear diffusion problems.

Chapter 5 focuses on elastostatics. The theory of elasticity, the fundamental integral equation statement (Somagliano identity), and stresses at internal points, basic equations for boundary element techniques, infinite and semi-infinite regions, boundary elements, and systems of equations are covered. A section on stresses on the boundary encompasses body forces (gravitational, centrifugal, and thermal loads) and axisymmetric problems. The next chapter covers the boundary integral formulation for inelastic problems. Materials in the plastic and creep range, governing force and moment equations, and formulation of the boundary integral are given. Alternate formulations include extension into half space and spatial discretization.

Chapter 7 employs BE equations derived in the previous chapter. The Von Misis yield criterion, Mendelson's successive elastic solution method, initial strain and stress formulations, and examples are presented. The authors show that boundary elements are best for problems with infinite domains and circular cavity pressure.

The next chapter considers other nonlinear problems including viscoelasticity. Examples are given of time-dependent problems and no-tension materials (rock-lined tunnels). Chapter 9 is a short chapter on plate bending and includes governing and integral equations as well as example problems. The reviewer would have liked to see BEM applied to circular plates. Chapter 10 covers wave propagation problems, three-dimensional wave-structure interaction, wave motion in vertical axisymmetric bodies, horizontal and vertical cylinders of arbitrary sections, and transient scalar wave equations; i.e., two-dimensional and the retarded potential in three dimensions.

Chapter 11 has to do with the BEM version of vibrations, or elastodynamics. Topics covered are time-dependent integral formulation, steady state (earth dams and foundations), and free vibrations (shear walls). The reviewer feels that this chapter is too short. Chapter 12 is concerned with advanced topics in fluid mechanics. Basic information is given in chapters 2, 3, 4, and 9. Topics in chapter 12 include complex formulation of nonlinearities, moving interface boundaries, axisymmetric bodies in cross flow, Stokes flow, and general viscous flow (steady and transient). The next chapter describes coupling of BE with various forms of the finite element method -- energy and Galerkin approaches. Examples include internal fluid-structure interaction and compressible flow. The chapter concludes with determinations of approximate FE and BE when fundamental solutions are difficult to obtain. The final chapter considers computer programs for two-dimensional elastostatics using linear boundary elements, i.e., elements with linear variations of displacements and tractions.

The reviewer has combined the results of his FE calculation of an inclined hole with BE results of the same inclined hole but having different acute angles to the horizontal. Peterson's results and plots of stress concentrations at the acute angle of the hole could be extended. This three-dimensional problem was checked by independent photoelastic measurements and the authors' test experiments on sample bars having the same physical dimensions as the FE solution. The reviewer feels that BEM applied to acoustic wave problems should have been included. This book is recommended to the newcomer to the field as well as those familiar which this powerful technique.

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EARTHQUAKE SOURCE MODELLING, GROUND MOTION AND STRUCTURAL RESPONSE

S.K. Datta, Ed.
ASME Pub. Vol. 80 (AMD-Vol. 60)
1984, 210 pp

This symposium presents results of recent investigations of analytical, numerical, and experimental techniques on the behavior of ground motion due to subsurface topographies and layering. Design of earthquake-resistant pipelines and oil and gas facilities plus the other aspects of earthquake engineering are also included. The symposium contained 14 papers.

The first paper describes recordings of ground motion in the immediate vicinity of fault. Hybrid modes are considered in which gross features of repetitive propagations are specified deterministically but are described by a stochastic model. The second paper presents analytical results of ground motion generated by sudden changes in the rate of advance of a curved front of a region sliding in an inclined fault plane; a two-dimensional canonical problem describes the elastic wave emission of a slip-displacement near the ruptured front. Both near- and far-field ground motions are considered. Paper #3 describes a modified version of the numerical integral approach in calculating the surface motion resulting for a multilayered half-space by a point dislocation. Special numerical techniques are used to accurately calculate body wave integrals at small specified distances and high frequencies.

Paper #4 considers the effects of geometry and surface layers. The author modifies general ray theory and applies it to waves in one or two wedge-shaped layers that overlay a half space. Paper #5 states that strong ground surface motion amplification depends upon a number of parameters: the contrast in material properties between layers, angle of incidence, location of observation point, and frequency of incident waves. The boundary integral equation approach is utilized. Paper #6 is concerned with scattering of SH waves by non-homogeneous surface obstacles of arbitrary shape in a half space. The author shows that relatively small changes in interface geometry can appreciably change the standing wave patterns of surface ground motion. He uses a numerical scheme to reduce the order of the system of equations to be solved.

Paper #7 states that scattering and radiation of elastic waves by arbitrarily shaped three-dimensional objects can be represented by a vector boundary integral equation. The integral formula is put in a form in which all singularities associated with the kernal are deleted. Examples illustrate the application. Paper #8 presents an efficient method using the boundary integral equation to study the effect of surface topographies on underground structures. A stable explicit integration scheme is used and no inversion of matrices is required. Paper #9 focuses on the numerical solution of an interface problem in which two differential equations are to be solved in adjacent regions. One region is infinite and is described by a wholly homogeneous equation. The anti-plane stress in an infinite region containing an inclusion is the most important ingredient of the elasticity problem. The authors employ a method that combines the finite element, boundary integral equation, and error analysis. Paper #10 considers that the near field is spatially described as a conventional finite element system. The outer region is represented by frequency-dependent stiffness matrices. This proposed algorithm treats separately the singular and regular portions of the kernal that describe the governing integro-differential equation.

Paper #10 considers the three-dimensional non-axisymmetric motion resulting from a plane longitudinal wave in an infinite medium. The plain strain problem is of a terminal of general shape buried in a semi-infinite medium and disturbed by a plane longitudinal wave. Large stresses and displacements are induced in soft ground; the angle of incidence greatly affects the response. In addition, the authors indicate that the beam model used to estimate stresses in a buried pipe is wholly inadequate. Paper #11 describes experiments to determine damage mechanisms of ductile steel pipe. The underground pipe was subjected to buried high explosives, and damage relationships were developed. They show that such pipe possesses much higher resistance to damage than brittle pipe. Similitude analyses were used to develop models of pipes subject to blast and ground loads. Measurements indicate that the soil significantly altered the dynamic response of the pipe compared to similar test results without soil. Tests with vacuum indicated that the density of the sand increased because air between sand particles was removed.

The last paper is concerned with the dynamic interactions due to earthquake behavior of buried pipes using a shell model. Two parametric studies were done to investigate the effects of pipe radius, slenderness of pipe, soil stiffness, and wave propagation or modal amplitudes.

This excellent symposium contains reports of analytical and experimental studies. The effects of seismicity on structures above and below ground are pointed out.

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SHORT COURSES

OCTOBER

RANDOM VIBRATION IN PERSPECTIVE — AN INTRODUCTION TO RANDOM VIBRATION AND SHOCK, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION, WITH EMPHASIS ON STRESS SCREENING
Dates: October 6-10, 1986
Place: Boston, Massachusetts
Dates: November 3-7, 1986
Place: Orlando, Florida
Dates: February 2-6, 1987
Place: Santa Barbara, CA
Dates: March 9-13, 1987
Place: Washington, D.C.
Dates: April 6-19, 1987
Place: Ottawa, Ontario
Dates: June 1-5, 1987
Place: Santa Barbara, CA
Dates: August 17-21, 1987
Place: Santa Barbara, CA
Dates: October 19-23, 1987
Place: Copenhagen, Denmark
Objective: To show the superiority (for most applications) of random over the older sine vibration testing. Topics include resonance, accelerometer selection, fragility, shaker types, fixture design and fabrication, acceleration/power spectral density measurement, analog vs digital controls, environmental stress screening (ESS) of electronics production, acoustic (intense noise) testing, shock measurement and testing. This course will concentrate on equipment and techniques, rather than on mathematics and theory. The 1984 text, "Random Vibration in Perspective," by Tustin and Mercado, will be used.

Contact: Wayne Tustin, 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 682-7171.

1986 JOHN C. SNOWDON VIBRATION CONTROL SHORT COURSE
Dates: October 20-24, 1986
Place: The Pennsylvania State University
Objective: This course, under the sponsorship of the Applied Research Laboratory, is presented by internationally known lecturers. It was initiated by the late Professor John C. Snowdon a decade ago and now continues under the guidance of Dr. Eric E. Ungar of Bolt Baranek and Newman, Inc. The course emphasizes principles, general approaches and new developments, with the aim of providing participants with efficient tools for dealing with their own practical vibration problems.

Contact: Gretchen A. Leathers, 410 Keller Conference Center, University Park, PA 16802 - (814) 863-4563

UNDERWATER ACOUSTICS/SIGNAL PROCESSING SHORT COURSE
Dates: October 27-31, 1986
Place: Pennsylvania State University
Objective: The course is designed to provide a broad, comprehensive introduction to important topics in underwater acoustics and signal processing. Among the topics to be presented are: an introduction to acoustic and sonar concepts; transducers and arrays; signal processing; active echo location; and turbulent and cavitation noise. Each of the nine instructors contributing to this course is actively involved in both the *theoretical and practical* aspects of the materials they present and will be happy to confer on individual questions or problems. Each participant will receive, for his retention, a bound set of lecture notes and three textbooks.

Contact: Alan D. Stuart, Course Chairman, at the Applied Research Laboratory, The Pennsylvania State University, P.O. Box 30, State College, PA 16804 - (814) 863-4128.

NOVEMBER

MACHINERY VIBRATION ANALYSIS I
Dates: November 11-14, 1986
Place: Chicago, Illinois
Dates: February 24-27, 1987
Place: San Diego, California
Dates: August 18-21, 1987
Place: Nashville, Tennessee
Dates: November 17-20, 1987
Place: Oak Brook, Illinois
Objective: This course emphasizes the role of vibrations in mechanical equipment instrumentation for vibration measurement, techniques for vibration analysis and control, and vibration

correction and criteria. Examples and case histories from actual vibration problems in the petroleum, process, chemical, power, paper, and pharmaceutical industries are used to illustrate techniques. Participants have the opportunity to become familiar with these techniques during the workshops. Lecture topics include: spectrum, time domain, modal, and orbital analysis; determination of natural frequency, resonance, and critical speed; vibration analysis of specific mechanical components, equipment, and equipment trains; identification of machine forces and frequencies; basic rotor dynamics including fluid-film bearing characteristics, instabilities, and response to mass unbalance; vibration correction including balancing; vibration control including isolation and damping of installed equipment; selection and use of instrumentation; equipment evaluation techniques; shop testing; and plant predictive and preventive maintenance. This course will be of interest to plant engineers and technicians who must identify and correct faults in machinery.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

1987

JANUARY

VIBRATION DAMPING TECHNOLOGY
Dates: January, 1987
Place: Clearwater, Florida
Objective: Basics of theory and application of viscoelastic and other damping techniques for vibration control. The courses will concentrate on behavior of damping materials and their effect on response of damped systems, linear and nonlinear, and emphasize learning through small group exercises. Attendance will be strictly limited to ensure individual attention.

Contact: David I. Jones, Damping Technology Information Services, Box 565, Centerville Branch USPO, Dayton, OH 45459-9998 - (513) 434-6893.

FEBRUARY

ROTATING MACHINERY VIBRATIONS
Dates: February 9-11, 1987
Place: Orlando, Florida
Objective: This course provides participants with an understanding of the principles and practices of rotating machinery vibrations and the application of these principles to practical problems. Some of the topics to be discussed are: theory of applied vibration engineering applied to rotating machinery; vibrational stresses and component fatigue; engineering instrumentation measurements; test data acquisition and diagnosis; fundamentals of rotor dynamics theory; bearing static and dynamic properties; system analysis; blading-bearing dynamics examples and case histories; rotor balancing theory; balancing of rotors in bearings; rotor signature analysis and diagnosis; and rotor-bearing failure prevention.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254.

APPLIED VIBRATION ENGINEERING
Dates: February 9-11, 1987
Place: Orlando, Florida
Objective: This intensive course is designed for specialists, engineers and scientists involved with design against vibration or solving of existing vibration problems. This course provides participants with an understanding of the principles of vibration and the application of these principles to practical problems of vibration reduction or isolation. Some of the topics to be discussed are: fundamentals of vibration engineering; component vibration stresses and fatigue; instrumentation and measurement engineering; test data acquisition and diagnosis; applied spectrum analysis techniques; spectral analysis techniques for preventive maintenance; signal analysis for machinery diagnostics; random vibrations and processes; spectral density functions; modal analysis using graphic CRT display; damping and stiffness techniques for vibration control; sensor techniques for machinery diagnostics; transient response concepts and test procedures; field application of modal analysis for large systems; several sessions on case histories in vibration engineering; applied vibration engineering state-of-the-art.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

MARCH

MEASUREMENT SYSTEMS ENGINEERING SHORT COURSE
Dates: March 9-13, 1987
Place: Phoenix, Arizona

Objective: Electrical measurements of mechanical and thermal quantities are presented through the new and unique Unified Approach to the Engineering of Measurement Systems. Test requestors, designers, theoretical analysts, managers, and experimental groups are the audience for which these programs have been designed. Cost-effective, valid data in the field and in the laboratory, are emphasized. Not only how to do that job, but how to tell when it's been done right.

Contact Peter K. Stein, Director, 5602 East Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603 and (602) 947-6333.

MEASUREMENT SYSTEMS DYNAMICS SHORT COURSE
Dates: March 16-20, 1987
Place: Phoenix, Arizona
Objective: Electrical measurements of mechanical and thermal quantities are presented through the new and unique Unified Approach to the Engineering of Measurement Systems. Test requestors, designers, theoretical analysts, managers, and experimental groups are the audience for which these programs have been designed. Cost-effective, valid data in the field and in the laboratory, are emphasized. Not only how to do that job, but how to tell when it's been done right.

Contact Peter K. Stein, Director, 5602 East Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603 and (602) 947-6333.

MAY

ROTOR DYNAMICS & BALANCING
Dates: May 4-8, 1987
Place: Syria, Virginia
Objective: The role of rotor/bearing technology in the design, development and diagnostics of industrial machinery will be elaborated. The fundamentals of rotor dynamics; fluid-film bearings; and measurement, analytical, and computational techniques will be presented. The computation and measurement of critical speeds vibration response, and stability of rotor/bearing systems will be discussed in detail. Finite elements and transfer matrix modeling will be related to computation on mainframe computers, minicomputers, and microprocessors. Modeling and computation of transient rotor behavior and nonlinear fluid-film bearing behavior will be described. Sessions will be devoted to flexible rotor balancing, including turbogenerator rotors, bow behavior, squeeze-film dampers for turbomachinery, advanced concepts in troubleshooting and instrumentation, and case histories involving the power and petrochemical industries.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

NOVEMBER

VIBRATIONS OF RECIPROCATING MACHINERY AND PIPING
Dates: November 10-13, 1987
Place: Oak Brook, Illinois
Objective: This course on vibrations of reciprocating machinery includes piping and foundations. Equipment that will be addressed includes reciprocating compressors and pumps as well as engines of all types. Engineering problems will be discussed from the point of view of computation and measurement. Basic pulsation theory -- including pulsations in reciprocating compressors and piping systems --will be described. Acoustic simulation in piping will be reviewed. Calculations of piping vibration and stress will be illustrated with examples and case histories. Torsional vibrations of systems containing engines and pumps, compressors, and generators, including gearboxes and fluid drives, will be covered. Factors that should be considered during the design and analysis of foundations for engines and compressors will be discussed. Practical aspects of the vibrations of reciprocating machinery will be emphasized. Case histories and examples will be presented to illustrate techniques.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

MODAL TESTING OF MACHINES AND STRUCTURES
Dates: November 17-20
Place: Oak Brook, Illinois
Objective: Vibration testing and analysis associated with machines and structures will be discussed in detail. Practical examples will be given to illustrate important concepts. Theory and test philosophy of modal techniques, methods for mobility measurements, methods for analyzing mobility data, mathematical modeling from mobility data, and applications of modal test results will be presented.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

NEWS BRIEFS: news on current and Future Shock and Vibration activities and events

CALL FOR PAPERS

POWER PLANT PUMPS SYMPOSIUM
MARCH 10-12, 1987
New Orleans, Louisiana

Abstracts on all power plant pump applications are being solicited. Abstracts should be from one-to-two typewritten pates in length and be submitted by September 16, 1986 for review. Authors of accepted papers ill be notified by October 1. A final camera ready copy of accepted papers will be due by January 31, 1987.

Mail abstracts to the Symposium Technical Coordinator: Maurice L. Adams, Department of Mechanical Aerosapce Engineering, Case Western Reserve University, Cleveland, OH 44106.

CALL FOR PAPERS

TWENTIETH MIDWESTERN MECHANICS CONFERENCE (20TH MMC)
August 31-September 2, 1987
Purdue University, West Lafayette, Indiana

Papers are solicited from all areas of mechanics, pure of applied, theoretical or experimental. Some of the topics of interest are mechanics of solids (elasticity, plasticity, vibrations, plates and shells, etc.), fluid mechanics (gas dynamics, turbulence, two-phase flow, etc.), acoustics (aerodynamic sound, wave guide acoustics, etc.), mechanics of interaction (fluid-structure dynamics, aeroelasticity, etc.), analytical and numerical methods (boundary value problems, probability, finite elements, etc.), experimental methods (photoelasticity, laser methods, modal analysis, etc.) and interdisciplinary mechanics (biomechanics, geomechanics, etc.). Papers summarizing or describing work in mechanics applied to problems of industrial research and development, and product design, are encouraged.

One page abstracts should be submitted before December 31, 1986 to Professors Hamilton and Soedel, School of Mechanical Engineering, Purdue University, West Lafayette, Indiana 47907, USA. As soon as possible after arrival of each abstract, authors will be notified about acceptance and will be sent special mats to type their paper on. The length of each paper should not exceed six pages. Full publication elsewhere is permitted.

The conference is sponsored by the School of Mechanical Engineering of Purdue University, in cooperation with the Schools of Aeronautical and Astronautical, and Civil Engineering.

REVIEWS OF MEETINGS

VIBRATION DAMPING WORKSHOP II

The Vibration Damping Workshop II was held in Las Vegas, NV, March 5-7, 1986. It was sponsored by the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories, and is was hosted by the Martin Marietta, Denver Aerospace Division. The following broad technical areas were covered:

Characterization and Properties of Damping Materials

Active Control of Structural Vibrations

Passive Damping Applications and Concepts

Identification of Structural Damping

The Opening Session included a Welcome and a Keynote Address. Col. Roger Hegstrom, Chief, Structures and Dynamics Division, Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, welcomed the attendees. He presented an overview of the structures and dynamics technology areas where damping has had, and continues to have, a significant role. Some of the key technical areas include aircraft structural integrity, the logistic support of aircraft, and the control of large space structure vibrations. He also provided examples of the use of damping for solving many types of structural vibration problems.

Mr. Jerome Persh, Staff Specialist for Materials and Structures, Office of the Undersecretary of Defense for Research and Engineering presented the Keynote Address on "The Department of the Defense Science and Technology Program in Spacecraft Materials and Structures." Mr. Persh divided his address into several areas. First he reviewed the funding for the various categories of materials and structures research. He continued with a list of future missions and their technology needs, and the research thrusts to support the missions. He provided several examples of the importance of developing the damping technology to support many of the future missions, and one of these is to learn more about the damping properties of composite materials.

The session, "Damping Materials Characterization" followed the Keynote Address. It contained papers on the properties of damping materials, methods for measuring the properties of damping materials, and processing and presenting damping materials data. J.B. Layton, J. Eichenlaub, and L.C. Rogers discussed standardizing the graphical presentation of damping material data, and they included the quality checks that must be performed to ensure valid data are obtained. M.F. Kluesener used a comparison of the properties of two types of damping materials that were obtained by several test methods as a means to assess the strengths and the limitations of the various test methods. R.S. Fersht, S.N. Fersht, and M. Denice described a simplified technique for determining the damping properties and the performance of rubber isolators for guidance components over a broad temperature range. M.L. Parin presented the properties of the damping materials that were used for the damping treatments in the PACOSS and the RELSAT programs. He also described the different testing techniques, and he assessed their strengths and their limitations. The next two papers in this session concerned methods and systems for measuring materials properties. B. Davis, C. DeMeersman, and J. Peters described a simplified procedure for measuring the stiffness and the damping properties of rubber, while C. Chesneau described automated test equipment for measuring the properties of many kinds of viscoelastic materials. R.L. Bagley and P.J. Torvik discussed the use of fractional calculus models of the behavior of viscoelastic materials for determining the structural response of damped systems. D.I.G. Jones concluded this session with an evaluation of the various test methods for obtaining damping material properties data. He discussed the influence of the various test methods on the materials properties measurements, he presented ways to determine the validity of the data, and he discussed methods for reducing the scatter in data (aside from only making a single measurement).

The "Damping in Systems" and the "Analysis and Design" sessions were held concurrently. The papers in the former session concerned the dynamic behavior of damping systems. L.P. Davis, J.F. Wilson, R.E. Jewell, and J.J. Roden described the development of a damped isolation system for isolating the Hubble Space Telescope from the low level axial vibrations produced by the reaction wheel assemblies. N.F. Rieger discussed the importance of gas-dynamic damping for reducing torsional vibrations of rigid and flexible steam turbine blades. Simple relationships were developed to allow designers to predict the level of gas-dynamic damping in the blades. A.E. Javid, J.L. Sackman, and J.L. Kelly described the design and evaluation of a composite material mechanical filter for isolating systems from high frequency vibrations, which is based on controlling the acoustic impedance of each layer of the composite material to only permit the passage of stress waves of certain frequencies. The other papers that were presented in this session were on the dynamic behavior of viscoelastic structures, damping and the nonlinear behavior of structures, and damping as a cause of instability.

Papers were presented in the session on analysis and design on the design of damped optical systems, the problems encountered in designing damping devices with viscoelastic components, and the effects of bonding imperfections on the dynamic response of laminated beams. J. Soovere discussed the damping mechanisms in acoustically excited riveted panels in multi-bay structures. He also described a method for predicting the variation in the damping with frequency for those structures. N.K. Frater described the use of the modal strain energy approach, combined with post processing with MSC/NASTRAN, to predict the dynamic characteristics and the response of a beam, partially covered with a constrained layer damping treatment. A.D. Reddy, J. Prucz, P. Smith, and L.W. Rehfield discussed the influence of temperature on the damping capability of structural joints with added viscoelastic damping treatments.

Mr. Robert Morra, Vice President Technical Operations, Martin-Marietta Corporation presented the Plenary Address on the second day of the conference. His title was, "The Role of Damping in National Space Strategy." He discussed future space activities and the dynamics challenges posed by large space structures and their associated sensors and experiments. He discussed the role of damping in controlling the vibration inputs to the sensors and the experiments, and he discussed the advances in the structural dynamics, and in the damping technology that would be needed to support the future space initiatives.

The session, "Damping in Space" followed the Plenary Address, and it contained papers on the use of passive damping treatments to control vibrations in large space structures, and the modal damping characteristics of space vehicles and space structures. H. Ashley and D.L. Edberg discussed the structural damping needs for controlling the dynamic response of large space structures. They considered the influence of the operating bandwidth of the control system and the availability of damping in monolithic and built-up structures to meet the damping needs of the control systems for large space structures. J.M. Hedgepeth and M. Mobrem described the use of continuous and partial constrained layer damping treatments, and dynamic absorbers, to augment the structural damping for controlling the vibrations of large space truss structures. E.D. Pinson presented the damping characteristics of a solar array panel which ere obtained during the Solar Array Flight Experiment modal test. D.W. Nicholson and M.G. Prasad described a proposed, simplified method for estimating modal damping coefficients by measuring resonance frequency shifts. B.K. Wada discussed the influence of different modal testing techniques on the values of the modal camping recovered from modal tests on several spacecraft that were developed by JPL. F.Y. Hadaegh, D.S. Bayard, and D.R. Meldrum discussed the use of modal data to identify the structural parameters of large space structures. D.R. Morgenthaler and R.N. Gehling described the analysis of the PACOSS Representative Structure which was designed to demonstrate use and the design of passive damping treatments for reducing both the jitter and the settling time of optical systems.

The session, "Vibration and Controls Interaction" and "Composites," were held concurrently. The papers in the former session concerned the role of active and passive damping in suppressing structural responses to control system inputs. P.J. Lynch and S.S. Banda discussed the contributions of active and passive damping for controlling structural vibrations and how the presence of passive damping affects the performance of active damping systems. R.N. Gehling examined the use of passive damping for controlling the vibrations in the Representative Large Space Structure. The results of the analyses of the settling times of optical experiments were used to compare performance of the actively damped, and the combination of actively damped and passively damped support structures. R.K. Yedevalli described the use of a state-space model to design a robust control system for suppressing the response of large space structures to attitude control system inputs. P.C. Hughes, D. Mc Tavish, K.W. Lips, and F.R. Vigneron described a new analytical approach for modeling viscoelastic damping in large space structures. D.W. Miller and E.F. Crawley discussed the passive and active control of structural vibrations using space-realizeable techniques. T.J. Brennan, P.R. Dahl, and J.J. Gerardi described the concept and the performance of a distributed multi-modal active damping system which uses thin-film piezo-electric actuators. P. Remington and E.F. Berkman described the use of pole allocation methods for controlling the vibrations of mechanical systems by developing a feedback control system to move the system natural frequencies away from critical excitation frequencies.

Mr. Samuel L. Venneri, Deputy Director for Materials and Structures, NASA Headquarters, presented the Plenary Address on the last day of the conference. He spoke on, "The NASA Perspective for Passive and Active Damping Requirements." He discussed some of the future needs in the active and passive damping technologies to support the development of future space vehicles and space structures, such as the National Aerospace Vehicle and the Space Station. Next, he reviewed many of the current NASA structural dynamics research efforts to support future space initiatives; a few examples include system identification of complex systems, structure-control system interaction, and the effect of actuator dynamics on the active control of spacecraft vibrations. He included a brief discussion of the "Control of Flexible Structures" (COFS) program which will be carried out in three phases, and which will be used to develop many of the analytical and test methods what will be necessary to support the development of future space vehicles and structures.

The session, "Damping in Structures" followed this Plenary Address, and it contained papers on methods for predicting the dynamic behavior of damped structures. R.A. Heller and M.P. Singh showed how a lumped mass-flexible beam model could be used to predict the bending and shear stresses in a solid propellant rocket motor that were induced by cross country transportation, and by helicopter aerodynamic loads. M.L. Drake and M.F. Kluesener presented an approach for determining the validity of damping materials properties data that were obtained by several test methods. J.M. Cuschieri and E.J. Richards presented a method for predicting the loss factors of coupled structures from measurements of the loss factors of each of the substructures, and the strength of the coupling between the substructures. This investigation was undertaken to provide a means for determining where to locate damping treatments so they will provide the most effective damping for the entire structure. L. Slivinski, G.A. Clark, and H.F. Chu described a hybrid modal synthesis method for identifying the modal damping and the other modal characteristics of deployed solar arrays. J.S. Hansen and K.J. Buhariwala discussed the development of a consistent damping matrix which they used in the dynamic analysis of a composite material cylindrical shell structure. K.R. Wentz, J. Lee, and S.R. Ibrahim showed how a random decrement approach could be used to identify the modal damping in a structure from its nonlinear responses to an unknown stationary input.

The title of the final session was "Applications for Space," and it included papers on the analysis and the tests of structures for the PACOSS and the RELSAT programs. C.D. Johnson and D.A. Keinholz described the modal analysis and the modal test of a damped generic truss structure. This effort was undertaken to prove the feasibility of using discrete damping devices to control the vibrations of space structures, and to evaluate the damping capability of a specific damping device. D.W. Johnson and R. Ikegami discussed the design of viable passive viscoelastic damping treatments for satellite equipment support structures. The objective of this study is to arrive at methods for designing damping treatments into equipment support structures to limit the vibration inputs to the equipment. In a companion paper, C.J. Beck, Jr. presented the results of vibration tests and pyrotechnic shock tests on a segment of an equipment structure to evaluate the performance of two types of damping treatments. J.A. Staley, J.C. Strain, and C.V. Sthale, Jr. presented the results of acoustic, pyrotechnic shock, and vibrations tests on a damped equipment support panel to evaluate the ability of the damping treatment to limit the dynamic inputs to the equipment. In a companion paper, the same authors compared the results of a modal test and a modal analysis on damped and undamped spacecraft equipment support panels. K.A. Schmidt presented a paper on the fabrication of damped spacecraft equipment panels. The author discussed the requirements and the criteria for selecting damping materials for space applications, and the inspection methods for ensuring the quality of the treated panels.

ADVANCE PROGRAM

57th SHOCK and VIBRATION

SYMPOSIUM

October 14–16, 1986

New Orleans, Louisiana

Hosts

Defense Nuclear Agency
Washington, DC

and

U.S. Army Engineer
Waterways Experiment Station
Vicksburg, Mississippi

Shock and Vibration
Information Center

GENERAL INFORMATION

CONFERENCE LOCATION: Registration, information and unclassified technical sessions are at the Monteleone Hotel, New Orleans, LA.

REGISTRATION: The registration fee must be paid before you get your badge. The registration fee covers the cost of the proceedings of the 57th Shock and Vibration Symposium. Since the registration fee covers the cost of the proceedings, there will be no reduced fee for part time attendance. The registration fee is $300.00. If you are an invited speaker, or an employee of the Defense Nuclear Agency or the Waterways Experiment Station, you are exempt from paying the registration fee. The registration fee may be paid by check, money order or cash only. Checks or money orders should be made payable to the Disbursing Officer, Naval Research Laboratory. We are sorry we cannot invoice for registration fees, and we cannot accept registration fees in forms other than those shown above.

On-Site Registration: Pre-registrants may obtain their badges or last minute registration may be accomplished at the following times.

Monteleone Hotel

Monday, October 13 -- 7:00 p.m.-9:00 p.m.
Tuesday, October 14 -- 7:30 a.m.-4:00 p.m.
Wednesday, October 15 -- 8:00 a.m.-4:00 p.m.
Thursday, October 16 -- 8:00 a.m.-2:00 p.m.

INFORMATION: The information and message center will be located in the registration area. The phone number at the hotel is (504) 523-3341. Telephone messages and special notices will be posted near the registration desk. All participants should check regularly for messages or timely announcements. Participants will not be paged in the sessions.

COMMITTEE MEETINGS: Space is available to schedule meetings for special committees and working groups at the Symposium. To reserve space, contact SVIC. A schedule of special meetings will be posted on the Bulletin Board.

SVIC STAFF:

Dr. J. Gordan Showalter, Acting Director
Mr. Rudolph H. Volin, P.E.
Mrs. Elizabeth McLaughlin (Secretary)

Shock and Vibration Information Center
Naval Research Laboratory, Code 5804
Washington, DC 20375
Telephone: (202) 767-2220
AUTOVON: 297-2220

SHOCK AND VIBRATION BULLETIN No. 57: Papers presented at the 57th Symposium will, at the author's request, be published in the Bulletin. Registrants who have paid the registration fee or have satisfied the registration requirements will receive a copy of the Bulletin.

57th SYMPOSIUM PROGRAM COMMITTEE

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Mr. John Robinson
U.S. Army Combat Systems Test Test Activity, STECS-EN-EV
Aberdeen Proving Ground, MD 21005-5059

TUESDAY, OCTOBER 14

8:30 a.m.
Queen Anne

Opening Session

This session is still being planned. Details will be available later.

2:00 p.m.
Queen Anne

Session 1A
Instrumentation

1. Shock-Isolated Accelerometer for Ground Motion Measurements - M.A. GROETHE, S-CUBED, La Jolla, CA

2. Shock-Isolated Accelerometer Systems for Measuring Velocities in High-G Environments - C.R. WELCH and H.G. WHITE, U.S. Army

Engineer Waterways Experiment Station, Vicksburg, MS

3. Rigid Body Gage Using Cellular Concrete for Internal Isolation - A.P. OHRT, C.R. WELCH, and H.G. WHITE, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

4. Damped Bar Gauge Development - C.F. PETERSEN and R.S. WILSON, S-CUBED, La Jolla, CA, and D.M. BOONE, SAIC, La Jolla, CA

5. A Self-Recording Digital Recorder for Use in a 1000G Environment - G. ROARK and S. HRONIK, Kaman Sciences Corporation, Colorado Springs, CO, and J. UNDERWOOD, Defense Nuclear Agency, Washington, DC

6. An Integration Test for Accelerometer Evaluation - E.C. HANSEN, David Taylor Naval Ship Research and Development Center, Portsmouth, VA

7. Spectral Density Estimates of Coarsely Quantized Random Vibration Data - T.J. BACA, Sandia National Laboratories, Albuquerque, NM

8. A Quantitative Method for Evaluating Sensor Layouts - D.G. RAPP, Westinghouse Electric Corporation, West Mifflin, PA, and T.F. CHWASTYK, Naval Sea Systems Command, Washington, DC

2:00 p.m.
La Nouvelle Orleans East

Session 1B
Shock Analysis

1. A Summary of Experimental Results on Square Plates and Stiffened Panels Subjected to Air-Blast Loading - R. HOULSTON and J.E. SLATER, Defence Research Establishment Suffield, Ralston, Alberta, Canada

2. In-Structure Shock in a Prototype Blast Shelter - S.A. KIGER and S.C. WOODSON, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

3. Blast Capacity Evaluation of Standard Glazing - G.E. MEYERS, Naval Civil Engineering Laboratory, Port Hueneme, CA and W.L. BEASON, Texas A&M University, College Station, TX

4. Response of Non-Reinforced Masonry Walls to Conventional Weapons - J.C. RAY, R. WALKER, and W.L. HUFF, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

5. Epic-2 Predicted Shock Environments of Nonperforating Ballistic Impact - E.F. QUICLEY, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD

6. Shock Loading of a Vessel by an Underwater Explosion - A Numerical Simulation Compared with a Full Scale Test - W. PFRANG and W. BERGERHOFF, Industrieanlagen Betriebsgesellschaft mbH, Ottobrunn, West Germany, and W. RYBAKOWSKI and J. FREERCKS, Federal Bureau for Military Technology and Procurement, Koblenz, West Germany

7. An Investigation into the Tripping Behavior of Longitudinally T-Stiffened Rectangular Flat Plates Loaded Statically and Impulsively --H.L. BUDWEG and Y.S. SHIN, Naval Postgraduate School, Monterey, CA

8. Retarded Potential Technique Applied for Shock Wave Loading of Doubly Symmetric Submerged Structures - W.W. WEBBON, Martin Marietta Baltimore Aerospace, Baltimore, MD, and M. TAMM, Naval Research Laboratory, Washington, DC

WEDNESDAY, OCTOBER 15

8:30 a.m.
Queen Anne

Plenary A

This session is still being planned. Details will be available later.

9:40 a.m.
Queen Anne

Session I
Methods

1:30 p.m.
Queen Anne

Session II
Case Histories

BACKGROUND: The nondevelopment item mode of military equipment acquisition is not new, but it has recently become more important because of the potential savings of money and time in fielding new systems. In some cases it is the mode of equipment acquisition of first choice. Nondevelopment items may be either commercial "off-the-shelf" items, or they may be foreign or domestically developed items already in service, but adapted to different applications.

Whatever the item of equipment, the procedures for qualifying such items of equipment for shock and vibration may differ from those used to qualify equipment acquired in the traditional manner. The purpose of this workshop will be to examine the process of qualifying nondevelopment items of equipment, and to consider the similarities and the differences in the process for qualifying both types of equipment.

Two technical sessions are organized for this workshop. The first session will deal with the methods for qualifying nondevelopment items for shock and vibration. The second session will include case histories which will provide insight into experiences in qualifying nondevelopment items for different applications. Further details on the paper titles and authors will be given later.

FORMAT: The format for both of these session will consist of a series of presentations by invited speakers, followed by a brief question period. An extended period for discussion will be available in each session after all presentations are made. Time will also be available at the end of the day for the session reporters for both sessions to sum up the highlights of their individual sessions.

9:40 a.m.
La Nouvelle Orleans West

Session 2A
Structural Dynamics

1. Qualification by Analysis of IUS Plume Deflectors - R.F. HAIN, Boeing Aerospace Company

2. Analysis of Reinforced Concrete Structures under the Effects of Localized Detonations - T. KRAUTHAMMER, University of Minnesota, Minneapolis, MN

3. Reinforced Concrete Arches under Blast and Shock Environments - T. KRAUTHAMMER, University of Minnesota, Minneapolis, MN

4. Dynamic Stress at Critical Locations of a Structure as a Criterion for Mathematical Model Modification - C.A. VICKERY, JR. and C.U. IP, TRW, Inc., Norton AFB, CA, and D.I.G. Jones, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, OH

5. Optimized Structure Design Using Reanalysis Techniques - J.C. REUBEN, F.H. CHU, and T.E. POLLAK, RCA Astro-Electronics, Princeton, NJ

6. Reliability of Structures with Stiffness and Strength Degradation - F.C. CHANG and F.D. JU, University of New Mexico, Albuquerque, NM

9:40 a.m.
La Nouvelle Orleans East

Session 2B
Isolation and Damping

1. A Study of Extensional Damping Performance Discrepancies in Certain Constrained-Layer Treatments - S.S. SATTINGER, Westinghouse R&D, Pittsburgh, PA

2. On Free Decay Damping Test - L. LU, R. PEREZ, and K. SCHNEIDER, Westinghouse Electric Corporation, Sunnyvale, CA

3. Response of a Sequential Damper to Shock Inputs - S. RAKHEJA and S. SANKAR, Concordia University, Montreal, Quebec, Canada

4. Liquid Spring Design Methodology for Shock Isolation System Applications - M.L. WINIARZ, The BDM Corporation, Albuquerque, NM

5. Transient Shock Analysis of Shipboard Equipment Supported by Nonlinear Resilient Mounts - R.E. HEPP and R.P. BROOKS, NKF Engineering, Inc., Essington, PA

6. Design and Test of a Spacecraft Instrument Shock Isolator - D. SCHIFF, N. JONES, and S. FOX, Assurance Technology Corporation, Carlisle, MA

2:00 p.m.
La Nouvelle Orleans West

Session 3A
Structural Dynamics II

1. A New Look at the Use of Linear Methods to Predict Aircraft Dynamic Response to Taxi over Bomb-Damaged and Repaired Airfields - J.J. OLSEN, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, OH

2. Frequency Response Functions of a Nonlinear System - D.A. DEDERMAN, T.L. PAEZ, and D.L. GREGORY, Sandia National Laboratories, Albuquerque, NM

3. System Characterization in Nonlinear Random Vibration - D.L. GREGORY and T.L. PAEZ, Sandia National Laboratories, Albuquerque, NM

4. An Interactive-Graphics Method for Dynamic System Modelling, Applying Consistency Rules -

M.D.C. DYNE, Institute of Sound and Vibration Research, Southampton, England

5. The Response of Two-Degree-of-Freedom Systems with Quadratic Nonlinearities to a Combination Parametric Resonance - A.H. NAYFEH and L.D. ZAVODNEY, Virginia Polytechnic Institute and State University, Blacksburg, VA

6. Dynamic Response of a Geared Train of Rotors Subjected to Random Support Excitations - S.V. NERIYA, R.B. BHAT, and T.S. SANKAR, Concordia University, Montreal, Canada

7. Computer Simulation and Experimental Validation of a Dynamic Model (Equivalent Rigid Link System) on a Single-Link Flexible Manipulator - R.P. PETROKA and L. CHANG, Naval Postgraduate School, Monterey, CA

8. The Dynamics of an Oscillating Four-Bar Linkage - P. TCHENG, NASA Langley Research Center, Hampton, VA

2:00 p.m.
La Nouvelle Orleans East

Session 3B
Shock Testing

1. *High-Velocity Reverse Ballistic Rocket* Sled Testing at Sandia National Laboratories - R.D.M. TACHAU, Sandia National Laboratories, Albuquerque, NM

2. Mechanical Impact: Theoretical Simulation and Correlation - G.L. FERGUSON, Sandia National Laboratories, Albuquerque, NM, and L.C. MIXON and F.W. SHEARER, Holloman AFB, NM

3. Measurement, Data Analysis, and Prediction of Pyrotechnic Shock from Pin-Pullers and Separation Joints - M.J. EVANS and V.H. NEUBERT, Pennsylvania State University, University Park, PA and L.J. BEMENT, NASA Langley Research Center, Hampton, VA

4. Facilities for Shock Testing of Nuclear Shelter Equipment in Switzerland - P. HUNZIKER, Defense Technology and Procurement Group, NC Laboratory, Spiez, Switzerland

5. Shock Tests of Concrete Anchor Bolts for Shock Resistant Applications in Protective Structures - P. HUNZIKER, Defense Technology and Procurement Group, NC Laboratory, Spiez, Switzerland

6. Performance of the Modified 19 Ft Diameter Thunderpipe Blast Simulator - F. MATHEWS, S. DOERR, and J. NAKOS, Sandia National Laboratories, Albuquerque, NM

7. Microcomputers in Shock Testing of Water Saturated Sands - W.A. CHARLIE, H. HASSEN, M. HUBERT, and D. DOEHRING, Colorado State University, Fort Collins, CO

8. Shock Induced Pore Water Pressure Increases in Water Saturated Soils - W.A. CHARLIE, T. BRETZ, G. VEYERA, and D. ALLARD, Colorado State University, Fort Collins, CO

THURSDAY, OCTOBER 16

8:30 a.m.
Queen Anne

Plenary B

This session is still being planned. Details will be available later.

9:40 a.m.
Queen Anne

Session 4A
Vibration Test Criteria

1. TECOM's Research Efforts in the Dynamic Environments - J.A. ROBINSON, U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD

2. The Development of Laboratory Vibration Test Schedules - Philosophies and Techniques - R.D. BAILY, U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD

3. Laboratory Vibration Test Schedules Developed beyond MIL-STD-810D - R.D. BAILY, U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD

4. A Proposed Technique for Ground Vehicle Packaged Loose Cargo Vibration Simulation - W.H. CONNON, III, U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD

5. Analysis of Shock and Vibration Environments for Cargo on C9B Transport Aircraft - T.J. BACA, J.W. DOGGETT, and C.A. DAVIDSON, Sandia National Laboratories, Albuquerque, NM

9:40 a.m.
La Nouvelle Orleans East

Session 4B
Modal Test and Analysis

1. Vibration of Structures through Modal Testing Coupled with Component Mode Synthesis - A. KAUSHAL and R.B. BHAT, Concordia University, Montreal, Quebec, Canada

2. Centaur G Prime Modal Test - M. TRUBERT, Jet Propulsion Laboratory, Pasadena, CA, A. CUTLER, General Dynamics Space Systems, San Diego, CA, C. ENGELHARDT, Structural Dynamics Research Corporation, San Diego, CA, R. MILLER, NASA Lewis Research Center, Cleveland, OH, and D. PAGE, General Dynamics Convair, San Diego, CA

3. Modal Testing and Analytical Validation of Desalinization Plant Equipment - J. KOMROWER, R. HEPP, and D. WRIGHT, NKF Engineering, Reston, VA and G. MAYERS, David Taylor Naval Ship Research and Development Center, Bethesda, MD

4. A State-of-the-Art Approach for Modal Testing Using Multiple Input Sine Excitation - D.L. HUNT, SDRC, Inc., San Diego, CA

2:00 p.m.
Queen Anne

Session 5A
Vibration Analysis and Test

1. Evaluation of Vibration Specifications for Acoustic Environments - L.T. NGUYEN and G.J. ZERONIAN, Northrop Corporation, Hawthorne, CA

2. Fatigue Effects of a Sine Sweep Test - A.E. GALEF, TRW, Redondo Beach, CA

3. Statistical Measures of Clipped Random Signals - T.L. PAEZ and D.O. SMALLWOOD, Sandia National Laboratories, Albuquerque, NM

4. Fully Turbulent Internal Flow Excitation of Pipe Systems - S.E. DUNN, J.M. CUSCHIERI, and E.J. RICHARDS, Florida Atlantic University, Boca Raton, FL

5. The Effects of Rotor Unbalance on the Vertical Motion of a Soft-Mounted Block - F.C. NELSON, Tufts University, Medford, MA, B.M. ANTKOWIAK, Charles Stark Draper Laboratories, Cambridge, MA, and M. NABOVI-NOORI, Worcester Polytechnic Institute, Worcester, MA

6. Investigation of Vibration Problems with Heterodyne Holographic Interferometer - R.A. MC LAUCHLAN, Texas A&I University, Kingsville, TX

7. The Disadvantages of Using Measured Vibration Data as Input Levels in a Laboratory Vibration Test - G.J. MARTIN, Hughes Aircraft Company, Canoga Park, CA

8. Generic Three Dimensional Sine Testing - R.J. GLASER and J.A. GARBA, Jet Propulsion Laboratory, Pasadena, CA, and A.M. FRYDMAN, Harry Diamond Laboratories, Adelphi, MD

2:00 P.M.
La Nouvelle Orleans East

Session 5B
Short Discussion Topics

This session is still being planned. Details will be available later.

ABSTRACTS FROM THE CURRENT LITERATURE

ABSTRACT CONTENTS

AVAILABILITY OF PUBLICATIONS ABSTRACTED

None of the publications are available at SVIC or at the Vibration Institute, except those generated by either organization.

Periodical articles, society papers, and papers presented at conferences may be obtained at the Engineering Societies Library, 345 East 47th Street, New York, NY 10017; or Library of Congress, Washington, D.C., when not available in local or company libraries.

Government reports may be purchased from National Technical Information Service, Springfield, VA 22161. They are identified at the end of bibliographic citation by an NTIS order number with prefixes such as AD, N, NTIS, PB, DE, NUREG, DOE, and ERATL.

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U.S. patents and patent applications may be ordered by patent or patent application number from Commissioner of Patents, Washington, D.C. 20231.

Chinese publications, identified by a CSTA order number, are available in Chinese or English translation from International Information Service, Ltd., P.O. Box 24683, ABD Post Office, Hong Kong.

Institution of Mechanical Engineers publications are available in U.S.: SAE Customer Service, Dept. 676, 400 Commonwealth Drive, Warrendale, PA 15096, by quoting the SAE-MEP number.

When ordering, the pertinent order number should always be included, <u>not</u> the **DIGEST** abstract number.

A *List of Periodicals Scanned* is published in issues, 1, 6, and 12.

MECHANICAL SYSTEMS

ROTATING MACHINES

86-1696
Solution for Torsional Vibrations of Stepped Shafts Using Singularity Functions
O. Bernasconi
Swiss Federal Institute of Technology, Lausanne, Switzerland
Intl. J. Mech., Sci., 28 (1), pp 31-39 (1986) 1 table, 12 refs

KEY WORDS: Shafts, Torsional vibrations

This paper gives a new viewpoint and calculation method for torsional vibrations of stepped shafts with attached rotors. The model has distributed, but discontinuous, parameters (both inertia and elasticity) including rigid thin disks. From the single governing equation of motion with derivatives in the generalized sense, simple and exact general forms of the frequency equations and of the mode shapes are extracted. This approach is the only way to demonstrate the orthogonality properties of the exact mode shapes. The modal superposition makes it possible to determine the torsional response of machine systems.

86-1697
Analysis of a Rotor System with Vertical Shaft
A. Tondl
Nat. Res. Inst. for Machine Design, Praha-Bechovice, Czechoslovakia
Strojnicky Casopis, 36 (6), pp 723-734 (1985) 4 figs, 3 refs (in Czech)

KEY WORDS: Rotors, Shafts

A simplified rotor system characterized in that the restoring force in the neighborhood of the central equilibrium position which, however, is not unique, is negative is analyzed. That means that the restoring force has a decentralizing effect, e.g., due to the labyrinth seal of the certain type of the water turbine runner. Both the gyroscopic effect and the destabilizing effect of the hydrodynamic force component of the bearings and the runner seal are considered. It is shown that both symmetric and asymmetric whirling vibrations can exist and that the vibrations can be synchronized in a very broad rotational speed interval, which means that self-excited vibration component is entirely quenched by the resonant vibration.

86-1698
The Effects of Bearing Geometry on Rotor Stability
J. Brindley, L. Elliott, J.T. McKay
Univ. of Leeds, Leeds, England
ASLE, Trans., 29 (2), pp 160-165 (Apr 1986) 8 figs, 9 refs

KEY WORDS: Journal bearings, Rotors, Whirling

The stability and unsteady behavior of journal bearings is much influenced by bearing geometry, and various designs have been used by engineers to promote stable bearing performance. The complexity of many of the bearing shapes used precludes anything other than purely numerical modeling if detailed quantitative results are sought for particular bearings. Much qualitative information on the general effect of bearing design is, however, obtainable from simple mathematical models in which the dominant physical effects of the geometry are retained. Such a model is described in which the effects of design features on the dynamics of the bearing can be exposed and understood in analytic terms. In particular, the effects on whirl instability of bearing shapes which influence cavitation of the lubricant are described. It is proposed that it is through the control of cavitation that bearing geometry exerts crucial effects.

86-1699
Startup of a Large Compressor Train -- Testing Verifies Design
J.C. Swalley
E.I. du Pont de Nemours & Co., Inc., Wilmington, DE
Turbomachinery Symposium, Proc. of the 14th, Texas A&M Univ., College Station, TX (Oct 22-24, 1985) (Spons. Turbomachinery Labs., Dept. M.E., Texas A&M) pp 65-72, 21 figs, 5 refs

KEY WORDS: Compressors, Testing techniques

The startup of a reliable compressor train involves not only the design and design audit, but also startup testing to verify the functionality of the design. Startup testing usually includes mechanical and electrical system checks, solo runs, alignment measurements, and extensive vibration monitoring. There are other test programs conducted at startup that can also pay an important role in the successful startup of a critical process train. Recently, a large compressor train was installed and brought on stream in an air oxidation process. Described briefly herein are five tests that helped verify the design and that are contributing to the

reliability of the train. These tests were: shaker testing a low tuned concrete foundation; transient torsional torque measurement during startup; measurement of stator vane stresses during surge; compressor surge tests; and measuring rated point performance.

86-1700
Shop vs. Field Correction to Equipment
C.P. Cook
Texaco, Inc., Houston, TX
Turbomachinery Symp., Proc. of the 14th, Texas A&M Univ., College Station, TX (Oct 22-24, 1985) (Spons. Turbomachinery Labs., Dept. M.E., Texas A&M) pp 47-50, 3 figs, 1 table

KEY WORDS: Compressors, Testing techniques

The objectives and types of shop testing for special purpose compressor trains are presented. Actual shop and field delays for various types of deficiencies are compared, and the period of time required to solve a problem at various stages of engineering is addressed.

86-1701
Scroll Compressor Dynamics: The Model for the Fixed Radius Crank
E. Morishita, M. Sugihara, T. Nakamura
Central Res. Lab., Amagasaki, Japan
Bull. JSME, 29 (248), pp 476-482 (Feb 1986) 9 figs, 1 table, 6 refs

KEY WORDS: Compressors, Air conditioning equipment

The scroll compressor has been introduced for an air conditioning application. This paper describes the dynamic behavior of the scroll machine with the fixed radius crank mechanism. The equations of motion are established for the orbiting scroll and the Oldham coupling, including the friction and the motion of the Oldham coupling, is shown. The bearing load, the torque and the power to drive the compressor are obtained. The overturning moment of the orbiting scroll is calculated and the stability condition is clarified.

86-1702
Scroll Compressor Dynamics: The Compliant Crank and the Vibration Model
E. Morishita, M. Sugihara, T. Nakamura
Central Res. Lab., Amagasaki, Japan
Bull. JSME, 29 (248), pp 483-488 (Feb 1986) 8 figs, 5 refs

KEY WORDS: Compressors, Air conditioning equipment

The compliant crank mechanism is employed for the scroll compressor to realize a tangential sealing. This paper presents a theoretical model for a scroll machine with a variable radius crank. The analytical expression is obtained for the radial sealing force. The Oldham coupling motion is transmitted to the orbiting scroll. The force and the torque which act on the rotating and stationary members of the compressor are shown. A simple tangential vibration model is introduced and examined numerically.

86-1703
Subsynchronous Vibration Problems in High-Speed, Multistage Centrifugal Pumps
I.C. Massey
Dresser Industries, Inc., Huntington Park, CA
Turbomachinery Symp., Proc. of the 14th, Texas A&M Univ., College Station, TX (Oct 22-24, 1985) (Spons. Turbomachinery Labs., Dept. M.E., Texas A&M) pp 11-16, 4 figs, 4 tables, 16 refs

KEY WORDS: Centrifugal pumps, Subsynchronous vibration

Subsynchronous vibration problems were experienced on two reactor charge pumps during on-site commissioning. This led to large whirl amplitudues, making the units automatically trip. A number of possible mechanisms of excitation were investigated. The problem was identified to be associated with the influence of the fine annular clearances in the machines on the stability of their rotors. The problem was rectified by making modifications to the annular seal configuration. Following an experimental test program, the machines were successfully recommissioned. A comprehensive analytical investigation into the stability of the rotor for varying seal configurations was carried out in parallel with the experimental test program. Agreement between analysis and test data was found to be good.

86-1704
Aeroelastic Effects in the Structural Dynamic Analysis of Vertical Axis Wind Turbines
D.W. Lobitz, T.D. Ashwill
Sandia National Labs., Albuquerque, NM
Rept. No. SAND-85-0957C, CONF-850834-2, 7 pp (1985) (WINDPOWER '85, San Francisco, CA, Aug, 1985) DE85017317/GAR

KEY WORDS: Wind turbines, Computer programs, Finite element technique, Aeroelasticity, Damping effects

Aeroelastic effects impact the structural dynamic behavior of vertical axis wind turbines in two major ways. First the stability phenomena of flutter and divergence are direct results of the aeroelasticity of the structure. Secondly, aerodynamic damping can be important for predicting response levels particularly near resonance but also for off resonance conditions. The inclusion of the aeroelasticity is carried out by modifying the damping and stiffness matrices in the NASTRAN finite element code.

86-1705
A Case Study in the Correlation of Analytical and Experimental Analysis
L.J. Petrick, A.D. Benz, S.G. Kensinger
Kensinger Assoc., Inc., Minneapolis, MN
S/V, Sound Vib., 20 (4), pp 24-31 (Apr 1986) 7 figs, 3 tables

KEY WORDS: Experimental modal analysis, Computer programs, Finite element technique, Fans, Motor vehicle engines

For engineers designing products, direct comparisons of test and analysis data have not been generally available. A means of mathematically integrating, statistically correlating, and comparing experimental modal analysis and finite element modal analysis data is needed. To illustrate the need for the approach to converging test and finite element methodology, a case study of an automotive engine fan assembly has been performed.

METAL WORKING AND FORMING

86-1706
Study of Thin Fluid Film Using Impulsive Load and Its Optimization for Noise Reduction in Forging
A. Daabdin, M.M. Sadek, D.L. Taylor
Univ. of Newcastle, U.K.
ASLE Trans., 29 (2), pp 246-255 (Apr 1986) 22 figs, 1 table, 6 refs

KEY WORDS: Forging machinery, Noise reduction, Oil film bearings

To reduce the transmission of impact energy in a drop forge from the impacting die to the anvil while retaining the deformation efficiency, a double-pad oil film has been developed and tested. The present paper is focused on the behavior of the oil film under an impulsive load. From the experimental apparatus, the measured pressure distribution over the bottom pad area is compared with that of theoretical results for both small and large gaps.

STRUCTURAL SYSTEMS

BRIDGES

86-1707
Impact in Railway Prestressed Concrete Bridges
K.H. Chu, V.K. Garg, T.L. Wang
Illinois Inst. of Tech., Chicago, IL
ASCE J. Struc. Engrg., 112 (5), pp 1036-1051 (May 1986) 17 figs, 4 tables, 13 refs

KEY WORDS: Railroad bridges, Prestressed concrete, Freight cars, Impact response, Moving loads

Ballasted prestressed concrete single track railway bridges, consisting of several box girders with spans of 25, 50, 75, and 100 ft were studied. The girder cross sections were designed according to American Railway Engineering Association (AREA) specifications. Two percent of critical damping corresponding to the first mode of vibration was assumed for the bridges. The track irregularities on the approaches and the bridges were generated from power spectral density function for Federal Railroad administration (FRA) Class 4 track. A freight car model, which included the geometric and suspension nonlinearities of the car, was developed and used in the analysis. Impact percentages in the bridges due to a two-vehicle, 100-ton freight car train operating at 20, 40, and 60 mph were calculated. These were compared with the values obtained in an earlier investigation and those specified by the AREA.

BUILDINGS

86-1708
Estimating Periods of Vibration of Tall Buildings
B.S. Smith, E. Crowe
McGill Univ., Montreal, PQ, Canada
ASCE J. Struc., Engrg., 112 (5), pp 1005-1019 (May 1986) 5 figs, 2 tables, 10 refs

KEY WORDS: Buildings, Seismic design

A hand method of estimating the period of free vibration of building structures, for use in determining the minimum base shear for their earthquake design, is presented. The method is for structures that have uniform properties through their height, and that are symmetrical in plan and symmetrically loaded so that they do not twist. The structures may consist of rigid frames, coupled walls, wall-frames and braced frames, or any combination of these. The basis of the method is that all of the above described types of bent behave as members of a family of shear-flexure structures whose static deflections can be predicted by coupled wall theory. A method of decoupling static deflection into a flexural component and a shear plus flexure wall-frame type of component is extended to dynamic behavior of a corresponding decoupled eigenvalue approach to determine the periods of free vibration. The derivation of the method, an assessment of its accuracy, and a worked example to illustrate its application are presented.

86-1709
Nonlinear Earthquake Analysis of Concrete Building Structures
D.P. Abrams
Univ. of Illinois, Champaign-Urbana, IL
80 pp, (Sep 1985) AD-A162 967/4/GAR

KEY WORDS: Buildings, Earthquake resistant structures, Concrete, Nonlinear response

The purpose of the study described in this report is to develop an analytical technique that considers explicitly both the history of the ground motion, and the nonlinear hysteretic behavior of the structure. The technique is developed using nonlinear resistance characteristics of reinforced concrete structures, however, the basis of the method is applicable to any type of building structure.

86-1710
Experimental Study of the Seismic Response of a Two-Story Flat-Plate Structure
J.P. Moehle, J.W. Diebold
California Univ., Richmond, CA
Rept. No. UCB/EERC-84/08, NSF/CEE-84030, 260 pp (Aug 1984) PB86-122553/GAR

KEY WORDS: Buildings, Plates, Reinforced concrete, Seismic response, Experimental data

A three-tenths scale, two-story reinforced concrete flat-plate structure was tested on the earthquake simulator at the Earthquake Engineering Research Center at the University of California, Berkeley. The test structure modeled a prototype structure with three bays in one direction and multiple bays in the transverse direction. The floor slab was supported on columns without interior beams, drop panels, or slab shear reinforcement. A shallow spandrel beam spanned the perimeter. The design seismic lateral forces were as specified for Zone 2 by the 1982 Uniform Building Code. The earthquake motions simulated were the North-South and vertical components of the El Centro, 1940 Imperial Valley earthquake. This report documents the design, fabrication, testing, and observed response of the test structure. Interpretations of the observed response are presented. Correlations obtained using modal analyses, linear elastic frame analyses, nonlinear frame analyses, and limit analyses are presented. Observations from isolated component experiments are summarized, and comparisons between component and test structure behavior are made.

FOUNDATIONS

86-1711
Deconvolution Method between Kinematic Interaction and Dynamic Interaction of Soil-Foundation System Based on Observed Data
K. Ishii
Shimizu Construction Co., Ltd., Tokyo, Japan
Shimizu Tech. Res. Bull., n3, pp 9-18 (Mar 1984) PB86-106671/GAR

KEY WORDS: Soil-foundation interaction, Deconvolution technique, Multi-degree-of-freedom systems, Buildings, Reinforced concrete

The general deconvolution method of kinematic interaction and dynamic interaction of a soil-foundation system, based on observed data is derived in the paper. The structure is modeled on a multi-degrees-of-freedom (MDOF) system which represents dynamic interaction and the unknown foundation input motion which is expressed by the moving average model (MA-model) of the ground motion. This represents the filtering effect of kinematic interaction. Generally, as the parameters of a MDOF system cannot be exactly determined, these parameters are determined as random variables on trial using the Monte Carlo simulation method. Next, the coefficients of MA-model are identified applying the Kalmon filter. Through many trials, results which minimize the root-mean-square errors between the observed response and calculated response are determined as best estimations. Examples of two single-degree-of-freedom systems arranged in a series of a four-story reinforced concrete school building are demonstrated as verification of the proposed method.

86-1712

Dynamic Structure-Soil-Structure Interaction Analysis by Boundary Element Method

H. Kawase, S. Nakai
Shimizu Construction Co., Ltd., Tokyo, Japan
Shimizu Tech. Res. Bull., n3, pp 19-25 (Mar 1984) PB86-106689/GAR

KEY WORDS: Soil-structure interaction, Boundary element technique

In this paper, the boundary element analysis for the effects which coupling through the ground may produce on the steady-state response of a structure located near a second structure is described. One of the most interesting features of the boundary element method is the much smaller resulting systems of equations to be solved. The method is also well suited for solving problems with infinite domains and complicated boundary conditions.

86-1713

Dynamic Analysis of a Structure Embedded in a Multilayered Medium by the Boundary Element Method

M. Hasegawa, S. Nakai, N. Fukuwa, T. Tamura
Shimizu Construction Co., Ltd., Tokyo, Japan
Shimizu Tech. Res. Bull., n4, pp 1-7 (Mar 1985) PB86-119732/GAR

KEY WORDS: Soil-structure interaction, Boundary element technique, Layered materials, Underground structures

The paper described an analysis procedure for a structure embedded in a multilayered medium using the boundary element method. The point load solution for this problem is derived from the semi-analytical finite element method which effectively uses the finite element approach by discretizing the soil layer into a number of thin horizontal layers. The accuracy of the results obtained by the present method is fairly good. This method is effective for the analysis of multilayered soil medium from standpoints of computational time and treatment for the layered structure. For the applications of this method, there is also discussion of a rigid structure embedded in a two-layered soil medium.

86-1714

Vibrations of Footings on Zoned Viscoelastic Soils

R. Abascal, J. Dominguez
Univ. of Seville, Seville, Spain
ASCE J. Engrg. Mech., 112 (5), pp 433-447 (May 1986) 8 figs, 1 table, 21 refs

KEY WORDS: Footings, Soil-structure interaction, Viscoelastic properties

Most finite element solutions of soil-structure interaction problems assume a horizontally layered soil that unavoidably extends to infinity and is bounded at the bottom by a bedrock. In this paper, a model consisting of a soil deposit included in a viscoelastic half-space is used to analyze numerically the effects of the shape of the soil deposit and the existence of a compliant bedrock on the dynamic compliances of strip footings. The soil deposit is assumed to be semielliptical and in order to achieve a parametric study several aspect ratios going from infinity (boundless horizontal layer) to one (semi-circle) are considered. The rigidity of the half-space is given several values including infinity (rigid bedrock). The foundation compliances are computed using a frequency domain formulation of the Boundary Element Method for zoned viscoelastic media.

HARBORS AND DAMS

86-1715

Study of the Earthquake Response of Pine Flat Dam

J.F. Hall
Caltech, Pasadena, CA
Earthquake Engrg. Struc. Dynam., 14 (2), pp 281-295 (Mar-Apr 1986) 11 figs, 1 table, 13 refs

KEY WORDS: Dams, Seismic response

The earthquake response of Pine Flat Dam is examined by a study of time history responses computed for a large set of earthquake ground acceleration records whose time axes have been systematically varied. Linear elastic behavior is assumed. Topics considered include an investigation of the importance of the presence of water, water compressibility and the vertical component of ground motion; an evaluation of the accuracy of the lumped, added mass representation of the water; and a determination of the intensity of earthquake required to initiate nonlinear behavior in both the dam and water.

86-1716

Analysis of the Response of Dams to Earthquakes

V. Lotfi

Ph.D. Thesis, Univ. of Texas at Austin, 207 pp (1985) DA 8527607

KEY WORDS: Dams, Seismic response, Finite element technique

A finite element method is developed for two-dimensional problems of dynamics of dam-reservoir-foundation systems taking into account all interactions rigorously. Reservoir-foundation interaction which previous developments have only simulated is considered by imposing the proper interface conditions, i.e., continuity of stress and displacement components normal to the interface. The method is applied to idealized configurations of dam-reservoir-foundation systems. A detailed study is conducted and the significance of dam-reservoir interaction, dam-foundation interaction, and especially, reservoir-foundation interaction effects is investigated.

86-1717
Dynamic Interaction Effects in Arch Dams
R.W. Clough, K.T. Chang, H.Q. Chen, Y. Ghanaat
California Univ., Richmond Earthquake Engineering Res. Ctr.
Rept. No. UCB/EERC-85/11, NSF/Eng-85026, 76 pp (Oct 1985) PB86-135027/GAR

KEY WORDS: Arch dams, Rock foundations, Structure-foundation interaction

The report summarizes the results obtained and the conclusions drawn from a four year cooperative research project on 'Interaction Effects in the Seismic Response of Arch Dams'. The central feature of the research was correlation of field measurements of the forced vibration response of two arch dams in China, Xiang Hong Dian and Quan Shui, with corresponding results predicted by computer analyses; the principal emphasis of the work was on the effects induced by dynamic interaction of the foundation rock and the reservoir water with the response of the dams.

86-1718
Earthquake Analysis of Arch Dams Including Dam-Water Interaction, Reservoir Boundary Absorption and Foundation Flexibility
Ka-Lun Fok, A.K. Chopra
Univ. of California, Berkeley, CA
Earthquake Engrg., Struc. Dynam., 14 (2), pp 155-184 (Mar-Apr 1986) 19 figs, 2 tables, 18 refs

KEY WORDS: Arch dams, Harmonic response, Seismic response, Substructuring methods, Computer programs

The available substructure method and computer program for the steady-state, harmonic response analysis of arch dams are extended to consider flexibility of the foundation rock. Fourier synthesis of harmonic response to obtain the earthquake response of arch dams are included. By efficient evaluation of hydrodynamic terms, interpolation of frequency response functions and efficient computer programming, the computational costs for analyzing arch dams are reduced relative to the available procedure.

POWER PLANTS

86-1719
Reliability Evaluation of Containments Including Soil-Structure Interaction
J. Pires, H. Hwang, M. Reich
Brookhaven National Lab., Upton, NY
Rept. No. BNL-NUREG-51906, 151 pp (Dec 1985) NUREG/CR-4329/GAR

KEY WORDS: Containment structures, Nuclear reactors, Soil-structure interaction, Reliability, Seismic response

Soil-structure interaction effects on the reliability assessment of containment structures are examined. The probability-based method for reliability evaluation of nuclear structures developed at Brookhaven National Lab. is extended to include soil-structure interaction effects. In this method, reliability of structure is expressed in terms of limit state probabilities. Furthermore, random vibration theory is utilized to calculate limit state probabilities under random seismic loads. Earthquake ground motion is modeled by a segment of a zero-mean, stationary filtered Gaussian white noise random process, represented by its power spectrum.

OFF-SHORE STRUCTURES

86-1720
Dynamic Response of Tension Leg Platforms with Axisymmetric Members
R.T. Hudspeth, J.W. Leonard
Oregon State Univ., Corvallis, OR
Engrg. Struc., 8 (1), pp 55-63 (Jan 1986) 7 figs, 1 table, 8 refs

KEY WORDS: Off-shore structures, Drilling platforms

Numerical algorithms have been developed from a Green's function solution for fixed structures of arbitrary shape. Numerical computations can be significantly improved for axisymmetric bodies by using an eigen-function expansion of the Green's function. A numerical algorithm is presented to compute the wave-induced forces and moments on large members of tension leg platform using an axisymmetric Green's function, and an option of using the relative motion Morison equation for selected members.

86-1721

A Proposed Stress History for Fatigue Testing Applicable to Offshore Structures

W.H. Hartt, N.K. Lin

Florida Atlantic Univ., Boca Raton, FL

Intl. J. Fatigue, 8 (2), pp 91-93 (Apr 1986) 3 figs, 2 tables, 6 refs

KEY WORDS: Off-shore structures, Fatigue tests

A fatigue loading spectrum proposed by Wirsching has been modified to yield a new spectrum more similar in appearance to the long-term stress history of deep water structures. The original spectrum was accelerated by omitting the three lowest sea states, combining the three highest stress states into one and raising the stress level. The test time history was developed using a Markov Chain model for sequencing between sea states.

86-1722

Response of Complaint Offshore Platforms to Waves

M. Grigoriu, B. Alibe

Natl. Bureau of Standards, Gaithersburg, MD

Rept. No. NBS/GCR-85/501, 66 pp (Sep 1985) PB86-130226/GAR

KEY WORDS: Off-shore structures, Drilling platforms, Water waves

Probabilistic descriptors are developed for the response of structures of the tension leg platform type to current and waves. These are obtained by Monte Carlo techniques by assuming the validity of the Morison equation. The results are compared to those obtained by using statistical linearization techniques. Mean upcrossing rates for various levels of structural response are estimated by simulation, statistical linearization techniques, and additional procedures developed in the report for offshore platforms with higher natural periods of vibration.

86-1723

Dynamic Behavior of a Floating Cable-Moored Platform Continuously Impacted by Ice Floes

M. Matsuishi, R. Ettema

Iowa Inst. of Hydraulic Res., Iowa City, IA

Rept. No. IIHR-294, 161 pp (Nov 1985) PB86-145380/GAR

KEY WORDS: Off-shore structures, Drilling platforms, Ice, Impact response

The principal objectives of the study were to determine the influences of floe diameter and speed on the ice-related loadings and motions (accelerations as well as displacements) that a conical platform would encounter while being continuously impacted by a field of annual-ice floes. Additionally, because a floating, moored platform can surge, pitch and heave when impacted by ice, the influences of platform motions on the ice loadings encountered by the platform were evaluated.

VEHICLE SYSTEMS

GROUND VEHICLES

86-1724

Device for Simulating Stress on Packages during Coupling of Railcars

M.T. Turczyn

Dept. of Agriculture, Washington, DC

U.S. Paten Appl. No. 4 545 236, 5 pp (Oct 1985)

KEY WORDS: Railroad cars, Shock response

A device for simulating railcar shock during coupling of freight cars comprising an inclined ramp, a backboard at the bottom of the ramp, a dolly to roll down the ramp into the backboard, a disposable hollow cylinder to be temporarily attached to the backboard or the dolly to be crushed there between when the dolly rolls into the backboard.

86-1725

Countermeasures Against Vibration and Noise in a Passenger Car with a Three-Cylinder Diesel Engine

T. Tsuto, Y. Ino, K. Abe

Daihatsu Motor Co., Ltd., Ikeda-shi, Japan

Intl. J. Vehicle Des., 7 (1/2), pp 67-85 (Jan-Mar 1986) 24 figs, 4 refs

KEY WORDS: Motor vehicles, Diesel engines, Vibration control, Noise reduction

This paper describes some of the problems encountered and the improvement made in pursuit of effective control methods of vibration and noise in three-cylinder diesel-powered passenger cars. Control measures taken at the engine side and the anti-vibration and noise insulation measures taken at the vehicle body side are documented.

AIRCRAFT

86-1726
Ground Vibration Test of the Laminar Flow Control JetStar Airplane
M.W. Kehoe, F.W. Cazier, J.F. Ellison
NASA Langley res. Ctr., Hampton, VA
Rept. No. NASA-TM-86398, 61 pp (Oct 1985) N86-13321/2/GAR

KEY WORDS: Aircraft, Vibration tests, Sine-dwell technique, Single point excitation technique, Frequency response function

A ground vibration test was conducted on a Lockheed JetStar airplane that had been modified for the purpose of conducting laminar flow control experiments. The test was performed prior to initial flight flutter tests. Both sine-dwell and single-point-random excitation methods were used. The data presented include frequency response functions and a comparison of mode frequencies and mode shapes from both methods.

86-1727
New and Existing Techniques for Dynamic Loads Analyses of Flexible Airplanes
A.S. Pototzky, B. Perry, III
PRC-Kentron, Inc., Hampton, VA
J. Aircraft, 23 (4), pp 340-347 (Apr 1986) 12 figs, 2 tables, 19 refs

KEY WORDS: Aircraft, Summation of forces method

This paper reviews existing techniques for calculating dynamic loads for flexible airplanes and presents a new technique. The new technique involves the summation-of-forces method of writing dynamic loads equations. Until now, this form of the dynamic loads equations has been formulated in the frequency domain. The new technique uses s-plane approximation methods (previously applied only to the equations of motion) to transform the dynamic loads equations from a second-order frequency domain formulation with frequency-dependent coefficients into a linear-time-invariant state-space formulation. Several numerical examples demonstrate the usefulness of the new technique and the high quality of the results. In addition, a convergence investigation establishes that the summation-of-forces method converges more quickly (that is, with fewer modes) than does the mode displacement method.

86-1728
A Review of Computer Simulations for Aircraft-Surface Dynamics
G.R. Doyle, Jr.
Univ. of Dayton, Dayton, OH
J. Aircraft, 23 (4), pp 257-265 (Apr 1986) 4 figs, 1 table, 54 refs

KEY WORDS: Aircraft, Computerized simulation, Force prediction, Displacement analysis, Computer programs

This report contains a brief summary of the computer programs written to predict the dynamic displacements and forces resulting from nonflight aircraft operations. The capabilities of each program along with their limitations and numerical techniques are cited.

86-1729
Resonance Fatigue Test of the Empennage of a CT4 Aircraft
I. Anderson, L. Molent
Aeronautical Res. Labs., Melbourne, Australia
Rept. No. ARL/STRUC-TM-412, 36 pp (June 1985) AD-A160 749/8/GAR

KEY WORDS: Aircraft, Fatigue tests, Resonance tests

A resonance fatigue test was carried out on the rear fuselage and empennage of a CT4 aircraft. The structure was supported in a reaction frame, and was excited at the resonant frequency of the fuselage torsional mode (9 Hz) by electromagnetic shakers connected to the tailplane. The loading spectrum applied was based on strain sequence data obtained from flight trials. Regular inspections of the structure were carried, out, and several areas on the rear fuselage and empennage were identified as being prone to fatigue damage.

86-1730
Flutter Generator Control and Force Computer
R.W. Levinge

Advanced Engineering Lab., Adelaide Australia
Rept. No. AEL-0242-TM, AR-004-156, AD-A161, 60 pp (Jul 1985) N86-15318/6/GAR

KEY WORDS: Aircraft wings, Wing stores, Active flutter control

The possibility of flutter induced by a store carried under the wing of an aircraft is investigated. This involves in-flight dynamic analysis of structural deformations at given points on an airframe due to forces originating in the store. A system of rotating eccentric masses generates a force spectrum 2.4 to 20.0 Hz in both horizontal and vertical axes. Electronically controlled, the Flutter Generator runs for 28 s with a swept frequency of force is computed continuously and telemetered to ground as an analogue signal.

86-1731
Application of Time-Linearized Methods of Oscillating Wings in Transonic Flow and Flutter
M.H.L. Hounjet, J.J. Meijer
National Aerospace Lab., Amsterdam, Netherlands
Rept. No. NLR-MP-84077-U, B8569322, 21 pp (Aug 1984) (AGARD Specialists Meeting on Unsteady Aerodynamics and Aeroelastic Applications, Toulouse, France, Sep 2-7, 1984) N86-16204/7/GAR

KEY WORDS: Aircraft wings, Airfoils, Flutter, Aerodynamic loads

Unsteady aerodynamic loads in the transonic domain were obtained with time-linearized methods in which a so-called field panel method which accounts for a proper radiation of signals towards infinity is embedded. The methods are used to predict the unsteady loads and first harmonic pressure distributions on an airfoil and a transport type wing. Results are correlated with data of unsteady experiments and of other calculation methods. Transonic flutter applications to a fighter-type configuration are described.

86-1732
Investigation of Adaptive Controllers for Helicopter Vibration and the Development of a New Dual Controller
P. Mookerjee, J.A. Molusis, Y. Bar-shalom
Connecticut Univ., Storrs, CT
Rept. No. NASA-CR-177377, 162 pp (Jan 1985) N86-16228/6/GAR

KEY WORDS: Helicopters, Vibration control, Control systems

An investigation of the properties important for the design of stochastic adaptive controllers for the higher harmonic control of helicopter vibration is presented. Three different model types are considered for the transfer relationship between the helicopter higher harmonic control input and the vibration output: nonlinear, linear with slow time varying coefficients, and linear with constant coefficients. The stochastic controller formulations and solutions are presented for a dual, cautious, and deterministic controller for both linear and nonlinear transfer models. Extensive simulations are performed with the various models and controllers. It is shown that the cautious adaptive controller can sometimes result in unacceptable vibration control. A new second order dual controller is developed which is shown to modify the cautious adaptive controller by adding numerator and denominator correction terms to the cautious control algorithm. The new dual controller is simulated on a simple single-control vibration example and is found to achieve excellent vibration reduction and significantly improves upon the cautious controller.

86-1733
Assessment of Aerodynamic and Dynamic Models in a Comprehensive Analysis
W. Johnson
NASA Ames Res. Ctr., Moffett, Field, CA
NASA-TM-86835, 39 pp (Oct 1985) N86-13286/7/GAR

KEY WORDS: Helicopters, Aerodynamic characteristics

The history, status, and lessons of a comprehensive analysis for rotorcraft are reviewed. The development features, and capabilities of the analysis are summarized, including the aerodynamic and dynamic models that were used. Examples of correlation of the computational results with experimental data are given, extensions of the analysis for research in several topics of helicopter technology are discussed, and the experiences of outside users are summarized. Finally, the required capabilities and approach for the next comprehensive analysis are described.

MISSILES AND SPACECRAFT

86-1734
Fluid Slosh Studies, Volume 2, Study of Slosh Dynamics of Fluid Filled Containers on Slowly Rotating Spacecraft
K. Ebert

ERNO Raumfahrttechnik G.m.b.H., Bremen, Fed. Rep. Germany
ESA-CR(P)-2077-V-2 N86-14550/5/GAR

KEY WORDS: Sloshing, Fluid-filled containers, Spacecraft, Liquid rocket propellants

Fuel sloshing during slow rotation of spacecraft is discussed. The theory for slowly rotating spacecraft is developed completely for the three-dimensional case with no rotational symmetry. Expressions for the axisymmetric case are also derived. The three-dimensional problem (tanks with offset from the spin axis) is solved numerically only for spherical tanks. Tanks on the spin axis can have an arbitrary axisymmetric shape. The stability of the system is analyzed. Two cases are distinguished: dynamic instability caused by parameter combinations; and instability caused by liquid viscosity. In the dynamically instable region, the eigenfrequency of the satellite motion and of the internal rotational motion of the liquid coincide. The time constant of the dynamic instability is much smaller than the time constant for the instability caused by the energy dissipation in the boundary layer of the liquid. The control of the attitude motion of rotating systems is easier for slow spin rate because time constants of the rotational motion of the liquid depend directly on the spin rate and are large for slow rotations; and the motion of the free surface is stabilized by surface tension effects.

86-1735
Nonlinear Analysis and Optimal Design of Dynamic Mechanical Systems for Spacecraft Application
K.D. Wilmert, M. Sathyamoorthy
Clarkson Univ., Potsdam, NY
Rept. No. AFOSR-TR-85-1017, 32 pp (Feb 1985)
AD-A162 194/5/GAR

KEY WORDS: Spacecraft, Finite element technique, Vibration analysis, Optimum design

A nonlinear finite element procedure has been developed for the dynamic vibrational analysis of planar mechanisms. The analysis takes into account the effects of geometric and material nonlinearities, vibrational effects and coupling of deformations. The effects of nonlinearities have been found to be significant on the dynamic behavior. Due to the complex nature of this nonlinear analysis procedure, an efficient optimal design approach using an optimality criterion technique was developed. The new optimization technique, called the Gauss Nonlinearly Constrained Technique, was developed in such a way that is applicable to design problems with nonlinear objective functions and constraints. The applicability of this method has been demonstrated with example problems consisting of objective functions of various complexities. Complete details of the nonlinear finite element procedure as well as the optimization technique are available in the appendix.

MECHANICAL COMPONENTS

ABSORBERS AND ISOLATORS

86-1736
Experimental Comparison of Passive Vibration Isolation Systems with Air Chamber Elements and Level Control (Meßtechnischer Vergleich passiver Schwingungisolationssysteme mit Luftkammerelementen und Niveauregelung)
W. Holzapfel, W. Settgast, W. Baetz
Konstruktion, 38 (4), pp 139-148 (Apr 1986) 14 figs, 2 tables, 15 refs (in German)

KEY WORDS: Vibration isolators

Significant system parameters of several passive pneumatic vibration isolation systems with level control are determined experimentally. These parameters are assigned frequency to the degree of damping D, and the restoring accuracy. A comparison with the manufacturers data shows that in several cases the recorded data are poorer than the given data. These discrepancies are caused by the characteristics of level controllers, which act as nonlinear springs attached parallel to the isolation element.

86-1737
Using Finite Element Analysis as a Design Engineering Tool
D.J. Prats
Dataproducts Corp., Milford, NH
S/V, Sound Vib., 20 (3), pp 28-32 (Mar 1986) 4 figs, 1 table

KEY WORDS: Supports, Finite element technique, Packaging, Business equipment

Plastic business machine packaging has traditionally been designed by the iteration of fabricated and molded hardware. This article gives a case history of how finite element analysis was used to design a business machine support structure before the hardware fabrication began. The analysis results realized a saving in both time and expense in the prototype/preproduction phase of the program.

86-1738
Disturbance Accommodating Controllers for Rotating Mechanical Systems
K.D. Reinig, A.A. Desrochers
Advanced Electronics Systems Lab., Adelphi, MD
J. Dynam. Syst., Meas. Control, Trans. ASME, 108 (1), pp 24-31 (Mar 1986) 15 figs, 17 refs

KEY WORDS: Active vibration control, Magnetic bearings, Shafts

The use of magnetic bearings for supporting a rotor-shaft system has let to increasing interest in active control schemes. In this work, two disturbance accommodating controllers are developed which minimize the vibration of the system due to the mass imbalance of the rotor. The first controller generates an estimate of the disturbance force arising from this mass imbalance and then cancels its effect through the magnetic bearings. This keeps the rotor displacement at zero but often at the expense of high bearing forces. The second controller remedies this by estimating the eccentricity and then applying a force to be controlled shaft end to offset the effect of the eccentricity. This requires the controlled shaft end to follow a path so that the rotor shaft pivots about the center of mass. Thus, the center of mass of the system does not translate and so a disturbance force never occurs. Therefore, a small magnetic bearing force can be used to control the vibration of a large rotor. Both methods are compared to conventional bearing strategies.

SPRINGS

86-1739
An Exact Solution for the Vibration of Helical Springs Using a Bernoulli-Euler Model
D. Pearson, W.H. Wittrick
Univ. of Aberdeen, Aberdeen, UK
Intl. J. Mech. Sci., 28 (2), pp 83-96 (1986) 2 figs, 1 table, 17 refs

KEY WORDS: Helical springs, Periodic response, Bernoulli-Euler method, Natural frequencies

A solution is obtained for the steady-state vibration behavior of uniform helical springs in which the following effects are ignored; deformation due to shear and axial loads, the rotational inertias of the cross-section, and static loads applied to the spring. A theory is developed for the evaluation of the dynamic stiffness matrix. Natural frequencies are found using an adaption of the Wittrick-Williams algorithm. Details of the method of calculation are discussed. Results are presented for natural frequencies, and are compared with values obtained using other methods and assumptions. The method of this paper is shown to be particularly efficient.

BLADES

86-1740
A Nonlinear Model of Aeroelastic Behavior of Rotor Blades in Forward Flight
A. Rosen, O. Rand
Technion-Israel Inst. of Tech., Haifa, Israel
Vertica, 10 (1), pp 9-21 (1986) 14 figs, 1 table, 3 refs

KEY WORDS: Rotor blades, Aerodynamic stability, Helicopter blades

The paper presents a nonlinear model of the aeroelastic behavior of rotor blades. This model is based on two submodels. The first one is a nonlinear structural/dynamic model while the second is a prescribed-wake unsteady aerodynamic model. These two submodels have been described previously in detail and therefore are described here only briefly. The paper concentrates on the method of combining these two submodels. Since these submodels are nonlinear and the steady state is of nonlinear periodic nature, there are certain difficulties in obtaining the final complete aeroelastic response. The iterative interactive approach which has been developed is presented. The different problems associated with this model are discussed. Two examples will be presented where the theoretical results are compared with existing experimental results. It will be shown that good agreement is obtained in most of the cases.

86-1741
Forced Response Analysis of an Aerodynamically Detuned Supersonic Turbomachine Rotor
D. Hoyniak
NASA Lewis Res. Ctr., Cleveland, OH
Rept. No. NASA-TM-87093, 24 pp (1985) N86-10019/5/GAR

KEY WORDS: Fan blades, Compressor blades, Aircraft engines, Fluid-induced excitation

In this report an analysis is developed to predict the flow-induced forced response of an aerodynamically detuned rotor operating in a supersonic flow with a subsonic axial component. The aerodynamic detuning is achieved by alternating the circumferential spacing of adjacent rotor blades. The total unsteady aerodynamic loading acting on the blading, as a result of the convection of the transverse gust past the airfoil cascade and the resulting motion of the cascade, is developed in terms of influence coefficients. This analysis is used to investigate the effect of aerodynamic detuning on the forced response of a 12-blade rotor, with Verdon's Cascade B flow geometry as a uniformly spaced baseline configuration. The results of this study indicated that, for forward traveling wave gust excitations, aerodynamic detuning is very beneficial, resulting in significantly decreased maximum-amplitude blade responses for many interblade phase angles.

86-1742
Prediction of Advanced Propeller Noise in the Time Domain
F. Farassat
NASA Langley Res. Ctr., Hampton, VA
AIAA J., 24 (4), pp 578-584 (Apr 1986) 7 figs, 21 refs

KEY WORDS: Propeller blades, Noise prediction, Time domain method

This paper presents a brief derivation of a formula for prediction of the noise of high-speed propellers in the time domain. This formula is based on the solution of a linear wave equation (Ffowcs Williams-Hawkings equation) assuming that the sources are located on the actual blade surface. An approximation of this formula, using the assumption that the sources are on the mean surface of the blade, is also presented which is considerably simpler than the full surface expression. Both the mean and full surface formulas are suitable for prediction of noise of supersonic sources on the blade. They were derived to overcome some of the practical numerical difficulties associated with other acoustic formulations. A discussion of coding these formulas for numerical work follows. Some comparison of predicted results with experimental data is also included which demonstrates the usefulness of the derived analytic expressions.

86-1743
Aerodynamics of Two-Dimensional Blade-Vortex Interaction
G.R. Srinivasan, W.J. McCroskey, J.D. Baeder
JAI Associates, Mountain View, CA
20 pp (1985) AD-A160 662/3/GAR

KEY WORDS: Helicopters, Propeller blades, Vortex-induced vibration, Aerodynamic loads

A computational procedure and some numerical results of unsteady interaction of a helicopter rotor blade with a Lamb-like vortex of finite viscous core in subsonic and transonic flows is presented. The interaction considered here is one of the limiting cases of a more complex interaction typically encountered on helicopter rotor blade. In this limit, the interacting flow field is considered to be unsteady but two-dimensional. Accordingly, unsteady, two-dimensional, thin-layer Navier-Stokes equations are solved using a prescribed-vortex method.

BEARINGS

86-1744
Theoretical and Experimental Comparison of Vapor Cavitation in Dynamically Loaded Journal Bearings
D.E. Brewe, B.J. Hamrock, B.A. Jacobson
NASA Lewis Res. Ctr., Cleveland, OH
Rept. No. NASA-TM-87121, 16 pp (1985) N86-11425/3/GAR

KEY WORDS: Journal bearings, Cavitation

Vapor cavitation for a submerged journal bearing under dynamically loaded conditions was investigated. The observation of vapor cavitation in the laboratory was done by high-speed photography. It was found that vapor cavitation occurs when the tensile stress applied to the oil exceeded the tensile strength of the oil or the binding of the oil to the surface. The theoretical solution to the Reynolds equation is determined numerically using a moving boundary algorithm. This algorithm conserves mass throughout the computational domain including the region of cavitation and its boundaries. An alternating direction implicit method is used to effect the time march. A rotor undergoing circular whirl was studied. Predicted cavitation behavior was analyzed by three-dimensional computer graphic movies. The formation, growth, and collapse of the bubble in response to the dynamic conditions is shown. For the same conditions of dynamic loading, the cavitation bubble was studied in the laboratory using high-speed photography.

86-1745
Finite Element Analysis of Turbulent Lubricated Hydrostatic Journal Bearings for Static and Dynamic Conditions
J.A. Kocur, P.E. Allaire

Univ. of Virginia, Charlottesville, VA
ASLE, Trans., 29 (2), pp 126-135 (Apr 1986) 10 figs, 5 tables, 14 refs

KEY WORDS: Journal bearings, Finite element technique, Turbulence

Hydrostatic journal bearings have been employed in several applications where the lubricant is a working fluid with low viscosity. The resulting turbulent flow can be analyzed by considering three major pressure drops: pressure drop across the orifice restrictor, pressure drop over the pocket edges, and pressure drop across the bearing lands. This paper presents a finite element analysis of bearings in the above category. The bearings considered here have axial grooves between the pockets and either one or two pockets per pad. Both static and dynamic bearing properties are calculated for example bearings.

86-1746
Calculating the Bearing Life for Opposed Mounts and Unsteady Loads
W.C. Orthwein
Southern Illinois Univ., Carbondale, IL
Computers Mech. Engrg, 4 (6), pp 56-58 (May 1986) 14 figs, 4 tables, 5 refs

KEY WORDS: Roller bearings, Ball bearings, Fatigue life, Computer programs

Microcomputer programs to determine the fatigue life of angular contact ball bearings and tapered roller bearings are included in this article.

86-1747
Radial and Thrust Bearing Practices with Case Histories
C. Jackson
Monsanto Co., Texas City, TX
Turbomachinery Symp., Proc. of the 14th, Texas A&M Univ., College Station, TX (Oct 22-24, 1985) (Spons. Turbomachinery Labs., Dept. M.E., Texas A&M) pp 73-85, 28 figs, 5 refs

KEY WORDS: Bearings, Case histories

Case histories for 13 selected bearing design conversions for specific end results are presented. They were selected out of a group of bearing designs over a 25 year span to give a varied array of non-repetitive case histories. In addition, some ideas for proper measurements are also included.

86-1748
Static and Dynamic Material Model for Elastohydrodynamic Bearing Calculations
S. Swinstra
Instituut TNO voor Werktuigkindige Constructies, Delft, Netherlands
Rept. No. IWECO-5076503, TDCK-79878, 61 pp (Dec 1984) N86-15676/7/GAR (in Dutch)

KEY WORDS: Elastomers, Elastohydrodynamic properties, Bearings, Stiffness coefficients, Damping coefficients

Possibilities and conditions to model the dynamic behavior of rubber and synthetic bearing race materials were investigated. Stiffness and damping coefficients of water lubricated propeller shaft bearings with elastic race are insufficiently known. Based on a literature review, nonlinear elasticity, high damping, and incompressible behavior is assessed. Clear differences between static and dynamic properties are noted. A dynamic model using a complex dynamic modulus of elasticity is described.

GEARS

86-1749
Analytical Investigation of a Turning Gear Mechanism During Engagement Due to Stick-Slip
D. Michalopoulos, N. Aspragathos, A.D. Dimarogonas
Univ. of Patras, Patras, Greece
Mech. Mach. Theory, 21 (2), pp 145-151 (1986) 6 figs, 3 refs

KEY WORDS: Gears, Stick-slip response, Rotors, Coefficient of friction

The dynamic behavior of a linear rotor with a complex turning gear, multidegree of freedom, similar to the turning gear mechanism of large turbomachinery, including backlash, was examined analytically. Clash-engagement and pre-engagement methods were considered. The coefficient of friction used in the analysis was a nonlinear function of speed and load for bearings operating in the mixed lubrication regime under stick-slip conditions. Shaft torque and turning gear teeth loading were considerably lower during pre-engagement. The use of constant coefficient of friction produced smoother but erroneous results.

86-1750
Effect of Transmission Design on Gear Rattle and Shiftability
T.G. Brosey, R.L. Seaman, C.E. Johnson, R.F. Hamilton

Borg-Warner Automotive, Inc., Muncie, IN
Intl. J. Vehicle Des., 7 (1/2), pp 45-66 (Jan-Mar 1986) 23 figs, 4 tables, 4 refs

KEY WORDS: Gears, Power transmission systems

The power input to a vehicular transmission is not constant. In addition to the mean torque and speed, there is a periodic torque component, which causes a periodic angular acceleration of the transmission input shaft. A theory that shows the relationship between gear rattle and the combined effects of this angular acceleration, the effective transmission inertia, and the transmission drag is developed. The detrimental effect of high effective transmission inertia upon gear rattle and shift effort is shown. A unique test stand which can evaluate the gear rattle tendency of a transmission is described. A computer model is presented which calculates the angular acceleration at the transmission input given the spring rate, damping, and inertia of the driveline components. Finally, an optimum arrangement of the transmission geartrain is described. This arrangement lowers the effective inertia of the transmission, thereby decreasing the tendency for gear rattle and reducing shift effort.

FASTENERS

86-1751
An Experimental Study to Demonstrate the Superior Response Characteristics of Mechanisms Constructed with Composite Laminates
C.K. Sung, B.S. Thompson, P. Crowley, J. Cuccio
Michigan State Univ., East Lansing, MI
Mech. Mach. Theory, 21 (2), pp 103-119 (1986) 26 figs, 35 refs

KEY WORDS: Linkages, Slider crank mechanisms, Four bar mechanisms, Flexural vibrations, Layered materials

A detailed experimental investigation is presented into the dynamic flexural responses of slider-crank and four-bar linkages constructed from steel, aluminum and two graphite-epoxy laminates. This is the first time that an experimental investigation has demonstrated that composite linked mechanisms have superior response characteristics to comparable mechanisms manufactured in the commercial metals, and also that this dynamic behavior is governed by the stiffness-to-density ratio of the link material.

SEALS

86-1752
Analysis and Testing for Rotordynamic Coefficients of Grooved Turbulent Annular Seals
C. Kim
Ph.D. Thesis, Texas A&M Univ., 186 pp (1985)
DA 8528337

KEY WORDS: Seals

An analysis for turbulent grooved seals was developed and tested to predict leakage and dynamic coefficients, as related to rotor dynamics. The grooved surface roughness pattern is formulated as an inhomogeneous directivity in surface shear stresses. The governing equations are expanded in the eccentricity ratio to yield zeroth and first order perturbation solutions. Comparisons between analysis and experimental data are carried out in terms of effective stiffness, effective damping, and effective inertia coefficients for both tapered and constant-clearance circumferentially-grooved seals. Agreement between tests results and analysis for net-damping coefficients is satisfactory, but the stiffness predictions have mixed results. Test results for a range of circumferential-grooving patterns show superiority in leakage performance, but inferiority in net damping coefficients, as compared to the smooth seal and damper seal.

86-1753
Dynamic Response of Film Thickness in Spiral-Groove Face Seals
E. Dirusso
NASA Lewis Res. Ctr., Cleveland, OH
Rept. No. NASA-TP-2544, 22 pp (Dec 1985)
N86-15313/7/GAR

KEY WORDS: Seals, Lubrication

Tests were performed on an inward- and an outward-pumping spiral-groove face seal. The film thickness response to seal seat motions was experimentally determined. Film thickness, seal seat axial motion, seal frictional torque, and film axial load were recorded as functions of time. The experiments revealed that for sinusoidal axial oscillations of the seal seat, the primary ring followed the seal seat motion very well. For a skewed seal seat, however, the primary ring did not follow the seal seat motion, and load-carrying capacity was degraded. Secondary seal friction was varied over a wide range to determine its effect on film thickness dynamics. The seals were tested with ambient air at room temperature and atmospheric pressure as the fluid medium.

86-1754

Rotordynamic Forces Developed by Labyrinth Seals

D.W. Childs, D.L. Rhode

Texas A&M Univ., College Station, TX

Rept. No. AFOSR-TR-85-1070, 187 pp (Nov 1984) AD-A162 160/6/GAR

KEY WORDS: Seals, Fluid-structure interaction, Force prediction, Force measurement

Numerous developments have been completed toward the accurate measurement and prediction of the fluid-structure-interaction forces on labyrinth seals. The test facility was refined and data acquisition was automated. Measurements were obtained of both stiffness and damping force coefficients for two labyrinth seal configurations operating with small rotor motion about its centered position. Only the cross-coupled damping coefficient exhibits significant sensitivity to shaft speed, and the coefficients increase monotonically with increasing supply-to-discharge pressure ratio. Fluid pre-rotation exhibits a strong influence on cross-coupled stiffness, which increases and decreases, respectively, with prerotation in and opposite to the direction of shaft rotation. Direct damping is less sensitive to fluid pre-rotation, and is generally largest for pre-rotation against the shaft direction.

86-1755

Analysis of the Static and Dynamic Behavior of a Magnetic Liquid Seal

F. Sorge

Universita di Palermo, Palermo, Italy

Meccanica, 20 (4), pp 291-302 (Dec 1985) 8 figs, 19 refs

KEY WORDS: Seals, Shafts

A rotating shaft seal, using ferrofluid between biconical truncated magnetic poles, is analyzed both in static and dynamic conditions.

STRUCTURAL COMPONENTS

CABLES

86-1756

Dynamic Response of Sagged Cables

S.A. Ali

Washington Univ., St. Louis, MO

Computers Struc., 23 (1), pp 51-57 (1986) 6 figs, 1 table, 14 refs

KEY WORDS: Cables, Finite element technique

The equations of motion of the cable are developed for the general case when the cable is supported at two different elevations and subjected to static and dynamic loads between supports. Nonlinear strain-displacement relationship is used, which accounts for the change in cable tension during motion. The equations of motion are solved using the finite difference method for fixed and movable support conditions. The time history of the three components of the displacement and tension in the sagged cable are determined for forcing functions. A suddenly applied uniform load constant with time is applied. A load varying sinusoidally with time is studied. A prescribed time history of motion of one end of cable is used.

86-1757

Nonlinear Deterministic and Stochastic Response of Cable Systems with Large Bodies under Hydrodynamic Loads

J.W. Leonard, H. Tuah

Oregon State Univ., Corvallis, OR

Engrg. Struc., 8 (2), pp 93-106 (Apr 1986) 9 figs, 45 refs

KEY WORDS: Cables, Off-shore structures, Oceans, Finite element technique

The nonlinear dynamic analysis of cable and 'cable-large body' systems, subject to both deterministic and nondeterministic loading, is presented in this study. Nonlinearities occur due to large displacements, material nonlinearity, lack of stiffness in compression, and nonconservative fluid loading. A finite element model is sued to model the cable and rigid motions of the large body. The linearized incremental equations of motion for linear elastic materials are derived and solution procedures for both static and dynamic analyses are presented. The stochastic response of the cable system is analyzed in the frequency domain. Cable vibrations were assumed to be small displacements about the static configuration.

86-1758

Measuring Submarine Optical Cable Tension from Cable Vibration

Haruo Okamura

NTT, Yokosuka City, Japan

Bull. JSME, 29 (248), pp 548-555 (Feb 1986) 20 figs, 1 table, 3 refs

KEY WORDS: Cables, Underwater structures, Vibration measurement

A new tension measuring system for submarine cables utilizing the lateral vibration frequency of cables to calculate their tension has been proposed. Cable bending stiffness, the pay out/recovery velocity of cables, and response time of the measurement have been examined on land and out-at-sea. The new tension meter thus developed is a handy system consisting of an optical vibration detector, conventional filter, and an F/V converter and recorder. It covers a wide range of tension from 10kN up to more than 100kN within an error of 10 percent. In conclusion, the new system was found to improve the reliability of submarine cable pay-out and recovery operations as well as to offer a safer and more accurate tension measuring method.

86-1759
Determination of the Resonance Spectrum of Elastic Bodies Via the Use of Short Pulses and Fourier Transform Theory
M. de Billy
Universite Paris, Paris Cedex, France
J. Acoust. Soc. Amer., 79 (2), pp 219-221 (Feb 1986) 4 figs, 1 table, 8 refs

KEY WORDS: Wires, Submerged structures, Resonant response, Fast Fourier transform

A method which permits a rapid determination of the resonance spectrum of submerged elastic cylindrical wires is described. A portion of the backscattering signal is selected by a gate, and the gated echo is Fourier-transformed into the frequency domain. Depending on the temporal position of the gate in comparison with the specular signal, either the form function or the resonance spectrum was determined.

BEAMS

86-1760
Theoretical Studies on Flexural Wave Propagation in Beams: A Comprehensive Review — Part I: Historical Background
M.M. Al-Mousawi
Univ. of Aberdeen, Aberdeen, Scotland
Shock Vib. Dig., 18 (4), pp 11-18 (Apr 1986) 107 refs

KEY WORDS: Beams, Flexural waves, Wave propagation

A comprehensive review related to the problems of flexural wave propagation in beams is presented in three parts. Part I is a historical background. Part II describes the use of Timoshenko beam theory, including the effect of shear distortion and rotatory inertia, for vibrational and transient analysis of beams. Part III covers elastic stress wave propagation in beams with discontinuities of cross section.

86-1761
Three-Dimensional Vibration Analysis of a Uniform Beam with Offset Inertial Masses at the Ends
D.K. Robertson
NASA Langley Res. Ctr., Hampton, VI
Rept. No. NASA-TM-86393, 71 pp (Sept 1985)
N86-10580/6/GAR

KEY WORDS: Beams, Natural frequencies, Mode shapes, Computer programs

Analysis of a flexible beam with displaced end-located inertial masses is presented. The resulting three-dimensional mode shape is shown to consist of two one-plane bending modes and one torsional mode. These three components of the mode shapes are shown to be linear combinations of trigonometric and hyperbolic sine and cosine functions. Boundary conditions are derived to obtain nonlinear algebraic equations through kinematic coupling of the general solutions of the three governing partial differential equations. A method of solution which takes these boundary conditions into account is also presented. A computer program has been written to obtain unique solutions to the resulting nonlinear algebraic equations. This program, which calculates natural frequencies and three-dimensional mode shapes for any number of modes, is presented and discussed.

86-1762
Vibrations of Beams with Elastic Contact
W. Ostachowicz, D. Szwedowicz
Technical Univ. of Gdansk, Gdansk, Poland
Computers Struc., 22 (5), pp 763-771 (1986) 8 figs, 5 tables, 9 refs

KEY WORDS: Beams, Longitudinal vibration, Flexural vibrations, Coulomb friction, Finite element technique

The object of the paper is to present a method of analysis of longitudinal and transverse vibrations of beams, taking into account Coulomb friction forces at the nodes. The beams have been modeled by finite elements. The analysis is provided with an algorithm and examples of calculations. There is a description of a computer program which was utilized during the calculations.

86-1763
Dynamic Analysis of Beams by the Boundary Element Method
C.P. Providakis, D.E. Beskos
University of Patras, Patras, Greece
Computers Struc., 22 (6), pp 957-964 (1986) 3 figs, 1 table, 9 refs

KEY WORDS: Beams, Boundary element technique, Flexural vibrations, Elastic foundations

Free and forced flexural vibrations of beams are numerically studied with the aid of the direct boundary element method. The free vibration case is treated as an eigenvalue problem, while the forced vibration one is treated with the aid of the Laplace transform. The structural dynamic response is finally obtained by a numerical inversion of the transformed solution. The effects of a constant axial force, external viscous or internal viscoelastic damping, and an elastic foundation on the response are also considered. Various numerical examples serve to illustrate the method and demonstrate its advantages and disadvantages.

86-1764
On the Understanding of Chaos in Duffings Equation Including a Comparison with Experiment
E.H. Dowell, C. Pezeshki
Duke Univ., Durham, NC
J. Appl. Mech., Trans. ASME, 53 (1), pp 5-9 (Mar 1986) 5 figs, 8 refs

KEY WORDS: Curved beams, Boundary value problems, Duffing oscillators

The dynamics of a buckled beam are studied for both the initial value problem and forced external excitation. The principal focus is on chaotic oscillations due to forced excitation. In particular, a discussion of their relationship to the initial value problem and a comparison of results from theoretical model with those from a physical experiment are presented.

86-1765
Dynamic Response of a Beam with a Crack Subjected to Four-point Impact Bending
M. Shibahara, Y. Matsui
Kanazawa Univ., Kanazawa, Japan
Bull. JSME, 29 (248), pp 370-376 (Feb 1986) 14 figs, 2 tables, 12 refs

KEY WORDS: Beams, Cracked media, Impact response, Photographic techniques, Bernoulli-Euler method

In an investigation on the fracture of a beam with an edge crack subjected to four-point impact bending, the dynamic behavior associated with the crack initiation, the crack propagation, the change of the dynamic stress intensity factor and others were studied by photoelastic method. As the result, the change of the phenomenon by the influence of impact rate and the difference compared with three-point impact bending were made clear. Moreover, the dynamic stress intensity factor of a steady crack under impact loading was analyzed by the Euler-Bernoulli beam theory and the validity of this theoretical calculation was confirmed by comparison with experimental results.

COLUMNS

86-1766
Bounds on Earthquake Response of Structures
G. Ahmadi
Clarkson Univ., Potsdam, NY
ASCE J. Engrg. Mech., 112 (4), pp 351-369 (Apr 1986) 8 figs, 1 table, 36 refs

KEY WORDS: Columns, Seismic response, Elastic systems, Lyapunov functions

Dynamics of an elastic structure subjected to simultaneous horizontal and vertical earthquake ground accelerations are considered. The Lyapunov method is used and several general bounds on the maximum responses are developed. Using a stored energy and an optimal Lyapunov function, specific bounds on the motion of multi-degree-of-freedom structures are obtained. Particular attention is given to the case of a single-degree-of-freedom column structure subjected to horizontal-vertical earthquake excitations. It is observed that the vertical acceleration enhances the peak horizontal response. The predicted bounds are compared with the response spectra of several earthquakes. It is shown that when an appropriate choice for the effective time duration is used the estimated maximum responses become quite reasonable.

86-1767
Passive Damping Concepts for Slender Columns in Space Structures
Z. Razzaq, R.K. Ekhelikar
Old Dominion Univ., Norfolk, VA
Rept. No. NASA-CR-176234, 137 pp (May 1985) N86-10577/2/GAR

KEY WORDS: Columns, Spacecraft, Damping coefficients

An experimental and theoretical study of three different passive damping concepts is conducted for a slender member with partial rotational end restraints. Over a hundred full-scale natural vibration experiments were conducted to evaluate the effectiveness of mass-string, polyethylene tubing, and chain damping concepts. The damping properties obtained from the experiments were used in the approximate analyses based on the partial differential equation of motion for the problem. The comparison of the experimental and the theoretical deflection-time relations shows that the velocity-dependent damping model used in the theory is adequate. From the experimental results, the effect of end connection friction and induced axial forces on damping is identified.

FRAMES AND ARCHES

86-1768

Elasto-Plastic Oscillator with Gaussian Excitation

O. Ditlevsen
Technical Univ. of Denmark, Lyngby, Denmark
ASCE J. Engrg. Mech., 112 (4), pp 386-406 (Apr 1986) 7 figs, 2 tables, 8 refs

KEY WORDS: Frames, Trusses, Elastic-plastic properties

The problem of calculating the plastic movement process is studied for a single-degree-of-freedom linear elastic-ideal plastic oscillator subject to stationary Gaussian process excitation. It is assumed that the events of plastic movements are rare and of short duration such that the movement process may be modeled as a compound Poisson process. The study concentrates on the calculation of the distribution of the single jumps of the process. The tool for this is the concept of Slepian model process displayed in several interesting applications, in particular by G. Lindgren and co-workers. Under certain general assumptions it may be concluded that the plastic displacement resulting from a single isolated exceedance of an elasticity limit as a first approximation has an exponential distribution. Special problems appear for narrow band response with clumping of level crossing. The problem is analyzed in some detail at the end of this paper.

PLATES

86-1769

Acoustic Excitation of a Square Plate by Turbulent Flow Noise

H. Fenech, I. Ganz
Univ. of California, Santa Barbara, CA
Appl. Acoust., 19 (3), pp 167-182 (1986) 12 figs, 4 refs

KEY WORDS: Rectangular plates, Fluid-induced excitation, Vortex shedding, Ducts, Noise generation

An experiment was conducted to measure the characteristics of flow noise in a bounded system with forced circulation. The flow noise facility is described herewith. Vortex shedding in the conducting rectangular ducting was experimentally controlled by the insertion of cylinders of various diameters and pitch perpendicular to the flow. The sound pressure level exciting an instrumented square plate parallel with the flow direction was measured, as well as the plate response.

86-1770

Study of the Vibrational Behavior of a Plate Exposed to a Fluid Flow Along One of its Faces (Etude du Comportement Vibratoire d'Une Plaque Soumise a UN Ecoulement Parietal sur Une Seule de Ses Faces)

J.H. Batis
Centre Technique des Industries Mecaniques, Senlis, France
Rept. No. CETIM-103-050, 29 pp (Feb 1985) N86-14547/1/GAR (in French)

KEY WORDS: Plates, Fluid-induced excitation

Vibration of a plate with fluid flow on one face is discussed. The risk of instabilities due to gas-structure coupling is considered. Aeroelastic and hydroelastic models are examined. The Dowell model is adopted and a numerical example of a 0.2m x 0.2m plate is presented. A water flow and two thickness are assumed. The developed formula shows the presence of instability characterized as divergence. It is recognized that the velocity limits calculated are rough approximations.

86-1771

Nonlinear Multimode Response of Clamped Rectangular Plates to Acoustic Loading

Chuh Mei, D.B. Paul
Old Dominion Univ., Norfolk, VA
AIAA J., 24 (4), pp 643-648 (Apr 1986) 6 figs, 1 table, 33 refs

KEY WORDS: Rectangular plates, Acoustic excitation, Random response

Large-deflection and multiple modes are included in this analysis in order to improve the prediction of the random response of clamped rectangular panels subjected to broadband acoustic excitation. The von Karman Large-deflection plate equations, Galerkin's method, and the equivalent linearization technique are employed in the development. Mean-square deflections, mean-square strains, and equivalent linear frequencies are obtained for rectangular panels at various acoustic loadings.

86-1772
The Onset of Oscillation of an Elastic Plate Lying Spread Out on a Liquid Layer Under a Vertical Periodic Motion
Eiji Hasegawa, Mikio Matsushita, Masatoshi Sekiguchi
Keio Univ., Yokohama, Japan
Bull. JSME, 29 (248), pp 556-564 (Feb 1986) 15 figs, 5 refs

KEY WORDS: Plates, Periodic response

A thin elastic plate lies spread out on a horizontally viscous liquid layer with a finite depth. The liquid layer is excited from its bottom by a vertical periodic force. In this paper, whether or not the elastic plate is excited parametrically is investigated theoretically and experimentally. The boundaries of the region of instability in the space of the amplitude and frequency of the imposed oscillation are found for the subharmonic response by a linear theory. They are dependent on the wave number of the disturbance. The critical amplitudes of the imposed oscillation, below which the plate is stable, have a minimum value with respect to the wave number of the disturbance. The critical condition for the onset of instability is determined by this minimum critical amplitude. These theoretical results are found to be in fairly good agreement with the experimental ones obtained by using a thin rubber plate.

86-1773
Free Vibration and Buckling Analysis of Plates by the Negative Stiffness Method
L.G. Tham, A.H.C. Chan, Y.K. Cheung
Univ. of Hong Kong, Hong Kong
Computers Struc., 22 (4), pp 687-692 (1986) 6 figs, 5 tables, 10 refs

KEY WORDS: Plates, Free vibration, Discontinuity-containing media

The problem of vibration and stability analysis of plates with abrupt change of thickness or with cutouts can be conveniently treated by the negative stiffness method, using the higher-order Mindlin plate element as the basic element. The method is simple and yet versatile, and its accuracy was fully tested against a number of numerical examples.

86-1774
Free Vibration Analysis of Point-Supported Plates by Vibration Testing Technique
G. Aksu
Univ. of Petroleum and Minerals, Dhahran, Saudi Arabia
Mech. Mach. Theory, 21 (2), pp 153-166 (1986) 6 figs, 3 tables, 12 refs

KEY WORDS: Plates, Swept sine wave excitation, Vibration tests, Natural frequencies, Mode shapes

Sweep sine-wave testing is applied for the identification of dynamic characteristics of a four-point-supported square plate with free edges. The idea behind the method is to make use of free vibration time-response data such as acceleration to determine the natural frequencies and associated mode shapes. To compare with the theoretical results, detailed experimental results have been obtained. The natural frequencies and associated mode shapes for the first five modes have been predicted, and the variation of natural frequencies with various support positions have been analyzed for the first symmetric and anti-symmetric modes. It is found that the experimental results are generally in reasonable agreement with the theoretical ones.

86-1775
Vibration of Annular Plates Partially Treated with Unconstrained Damping Layer
N. Ganesan, S.N. Rao
Indian Inst. of Tech., Madras, India
Computers Struc., 23 (1), pp 87-93 (1986) 1 fig, 7 tables, 11 refs

KEY WORDS: Annular plates, Layer damping, Viscoelastic damping

Mass and stiffness matrices of an annular element consisting of base plate and unconstrained damping layer have been derived assuming a modal solution to the equation of motion of the plate. The complex eigen equations have been solved for frequencies and loss factors by an extension of the simultaneous iteration technique. Frequencies of unlayered plates and loss factors of fully layered plates have been compared with those available in literature. The effect of staggering of layers on the vibration characteristics of the plate has been investigated. It is

found that when the plate is partially layered starting from its inner edge loss factors will be higher for all boundary conditions and modes than when the plate is fully layered, provided the mass of the damping layer is kept the same in both cases.

86-1776
Nonlinear Axisymmetric Vibration of Orthotropic Thin Circular Plates with Elastically Restrained Edges
P.C. Dumir, Ch.R. Kumar, M.L. Gandhi
Indian Inst. of Tech., Delhi, India
Computers Struc., 22 (4), pp 677-686 (1986) 9 figs, 4 tables, 24 refs

KEY WORDS: Circular plates, Variable cross section, Elastic restraints, Nonlinear theories, Axisymmetric vibrations

This paper deals with the large-amplitude axisymmetric free vibrations of cylindrically orthotropic thin circular plates of varying thicknesses with edge elastically restrained against rotation and in-plane displacement. Geometric nonlinearity due to moderately large deflections is included. Linear, parabolic and cubic variations of thickness are considered. Harmonic vibrations are assumed and time is eliminated from von Karman-type governing equations by the Kantorovich averaging method. The orthogonal point collocation method is used for spatial discretization. Results are presented for the linear frequency or first axisymmetric mode and for the amplitude-period response. The effect of taper ratio, orthotropic parameter and rotational and in-plane stiffness of the support of the nonlinear vibration behavior is investigated.

86-1777
Factors Influencing the Ultrasonic Stress Wave Factor Evaluation of Composite Material Structures
C.J. Rebello, J.C. Duke,Jr.
National Technical Systems, Hartwood, VA
J. Comp. Tech. Res., 8 (1), pp 18-23 (1986) 9 figs, 2 tables, 8 refs

KEY WORDS: Composite materials, Plates, Resonant frequencies, Finite element technique, Stress waves

Some of the factors influencing the stress wave factor measurement and other integrative techniques are boundary conditions, type of damage, severity of damage, and area of damage. This paper suggests that a finite-element model can be used to study some of the factors influencing the ultrasonic stress wave evaluation of materials. To demonstrate this, a hypothetical case of the resonant frequencies on damaged and undamaged plates was studied. Finite-element modeling, which is the most widely used technique for incorporating local discontinuities, was used.

86-1778
Vibration and Buckling of Skew Plates with Edges Elastically Restrained Against Rotation
T. Mizusawa, T. Kajita
Daido Inst. of Tech., Nagoya, Japan
Computers Struc., 22 (6), pp 987-994 (1986) 4 figs, 4 tables, 21 refs

KEY WORDS: Skew plates, Elastic restraints, Vibration response, Spline technique, Strip method

This paper deals with vibration and buckling analyses of skew plates with edges elastically restrained against rotation using the spline strip method. The effect of rotational stiffnesses, skew angles and aspect ratios on these problems is analyzed, and its characteristic charts are also presented.

86-1779
Transient and Multiple Frequency Sound Transmission Through Perforated Plates at High Amplitude
A. Cummings
Univ. of Missouri-Rolla, Rolla, MO
J. Acoust. Soc. Amer., 79 (4), pp 942-951 (Apr 1976) 15 figs, 11 refs

KEY WORDS: Plates, Hole-containing media, Sound waves, Wave transmission

The transmission of complex periodic and transient acoustic signals through orifice plates at high amplitude, and in the absence of mean fluid flow, is discussed. A simple fluid dynamical model, involving a time-varying mass end correction, is the basis of the theory. The equation of motion for the air in the orifice is solved numerically in the time domain. For a specific instance, an analytical solution in the frequency domain is possible. Good agreement is noted between experimental and theoretical results in both time and frequency domain.

SHELLS

86-1780
The Effect of Hydrostatic Pressure Fields on the Structural and Acoustic Response of Cylindrical Shells
R.F. Keltie

North Carolina State Univ., Raleigh, NC
J. Acoust. Soc. Amer., 79 (3), pp 595-603 (Mar 1986) 21 figs, 2 tables, 11 refs

KEY WORDS: Cylindrical shells, Submerged structures, Sound waves, Wave radiation, Acoustic response

The effects of external hydrostatic pressure fields and fluid loading on the structural and acoustic response of a point-driven infinitely long circular cylindrical shell were examined over a range of frequencies. The external pressure field was modeled using static prestress terms in the shell equations of motion, and the structural response was characterized by the driving point admittance and the circumferential resonant frequencies. The acoustic response was quantified through calculation of the radiated sound power, both in an overall sense and on an individual modal basis. The analysis was performed for the in-air case as well as for the in-water case. The structural response was found to be strongly affected by fluid and pressure, resulting in significant resonant frequency shifts. However, the overall acoustic response was shown to be nearly independent of the external pressure field, both in air and in water. In addition, is was shown that relatively fewer modes contribute significantly to the sound radiation for the submerged shell as compared to the shell in air. In both cases, the sound generation was controlled by the low-order nonresonant modes.

86-1781
Vibration Analysis of Fluid-coupled Two Coaxial Axisymmetric Shells Containing Fluid
Katsuhisa Fujita
Mitsubishi Heavy Industries, Ltd., Takasago, Japan
Bull. JSME, 29 (248), pp 516-524 (Feb 1986) 7 figs, 5 tables, 10 refs

KEY WORDS: Shells, Concentric structures, Fluid-filled containers, Seismic response

This paper presents a vibration response analysis method of fluid-coupled coaxial axisymmetric shells subjected to a horizontal earthquake. The kinetic energy and the strain energy of two coaxial axisymmetric shells are calculated by the finite element method. On the other hand, the velocity potential of the liquid contained in two shells is obtained analytically by assuming it is an ideal fluid, that is incompressible and inviscid, and then the kinetic energy of the liquid is calculated. Substituting these energies into Lagrange's equation of motion, the seismic response analysis method for a structure-liquid coupled vibration system is derived. As a result of numerical studies, this solution is proved to be an effective and reasonable method, and the seismic response characteristics of the two coaxial axisymmetric shells containing liquid are made clear.

PIPES AND TUBES

86-1782
Modal Combination in Response Spectrum Analysis of Piping Systems
A.K. Gupta, J.-W. Jaw
North Carolina State Univ., Raleigh, NC
J. Pressure Vessel Tech., Trans. ASME, 108 (1), pp 73-77 (Feb 1986) 1 fig, 3 tables, 7 refs

KEY WORDS: Pipelines, Modal analysis, Spectrum analysis

Modal combination methods in the response spectrum analysis of piping systems have been investigated. The residual rigid response and the correlation between the modal response and the rigid response are identified. Gupta's method accounts for both these effects. It is shown that Gupta's method gives results which are much closer to the direct integration analysis results than are the results obtained from any other modal combination rules which ignore either one or both of the foregoing effects.

DYNAMIC ENVIRONMENT

ACOUSTIC EXCITATION

86-1783
Environmental Noise Measurements
P. Bernard
Tech. Rev. (B&K), (1), pp 3-36 (1986) 19 figs, 5 tables, 12 refs

KEY WORDS: Noise measurement, Traffic noise, Aircraft noise, Measurement techniques, Measuring instrumentation

This article reviews the most common environmental noise rating methods, with special emphasis on the basic quantities recommended by the ISO standard 1966/1, and describes the application of the Noise Level Analyzer Type 4427 to a number of practical measurement situations. In the appendix the evaluation of the sound exposure level of a moving source under various conditions is outlined.

86-1784
Finite Element Modeling of Acoustic Singularities with Application to Propeller Noise
W. Eversman, J.E. Steck
Univ. of Missouri, Rolla, MO
J. Aircraft, 23 (4), pp 275-282 (Apr 1986) 10 figs, 1 table, 16 refs

KEY WORDS: Finite element technique, Noise source identification, Propellers

Numerical formulations and results that expand on recent developments in finite element modeling of acoustic volume sources and acoustic dipoles are presented. It is shown that with suitable structuring of acoustic field equations, it is possible to include monopoles and dipoles within the same analysis framework extensively used for interior duct acoustic and duct inlet radiation problems. This allows the extension of the finite element modeling method to include the noise sources in such applications as propellers enclosed in a duct or in free space with mean flows. The necessary structuring of the acoustic field equations is shown, and example calculations are given for the case of one-dimensional sources and body forces in the presence of mean flow, two-dimensional sources, axial body forces, and transverse body forces in the presence of uniform mean flow. Three-dimensional sources and dipoles are modeled as the Fourier sum of axially symmetric solutions without the necessity of introducing singular elements. It is further demonstrated that distributions of singularities can be readily modeled, and an example is given of the computation of the near-and far-field radiation of a propeller. Comparison of the far-field radiation directivity is made with the Gutin theory.

86-1785
A Review: Acoustic Emission, a Tool for Composite-Materials Studies
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Exptl. Mech., 26 (1), pp 7-13 (Mar 1986) 9 figs, 55 refs

KEY WORDS: Acoustic emission, Composite materials, Failure detection

The technique of acoustic emission has two broad applications areas. The first is nondestructive evaluation. The second is as a tool in studies or research which are not fundamentally directed towards acoustic emission. It is this second application with which we are concerned here. Acoustic emission is a very useful tool in this role because of its high sensitivity, real-time capability, volume-monitoring approach, and sensitivity to any process or mechanism which generates sound waves. This paper presents a comprehensive review of areas where acoustic emission has been used for materials studies on composite materials.

86-1786
Analytical Study of Acoustic Response of a Semireverberant Enclosure with Application to Active Noise Control
T.L. Parrott, D.B. Schein, D. Gridley
NASA Langley Res. Ctr., Hampton, VA
Rept. No. NASA-TP-2472, 48 pp (Dec 1985) N86-16040/5/GAR

KEY WORDS: Enclosures, Acoustic response, Active noise control

The acoustic response of a semireverberant enclosure with two interacting, velocity-prescribed source distributions was analyzed using standard modal analysis techniques with a view toward a better understanding of active noise control. Different source and enclosure dimensions, source separations, and single-wall admittances were studied over representative frequency bandwidths of 10Hz with source relative phase as a parameter. Results indicate that power radiated into the enclosure agree qualitatively with the spatial average of the mean square pressure, even though the reverberant field is nondiffuse. Decreases in acoustic power can therefore be used to estimate global noise reduction in a nondiffuse semireverberant environment.

86-1787
Excitation of Surface Waves of Different Modes at Fluid-porous Solid Interface
M.J. Mayes, P.B. Nagy, L. Adler
Ohio State Univ., Columbus, OH
J. Acoust. Soc. Amer., 79 (2), pp 249-252 (Feb 1986) 4 figs, 1 table, 9 refs

KEY WORDS: Interface: solid-fluid, Sound waves

The presence of ultrasonic surface waves of various modes on a fluid-porous solid interface is demonstrated and their velocities measured. The experimental technique utilizes reflected broadband spectra from periodic surfaces. Three sharp minima corresponding to three mode-converted waves coupled to the porous solid are observed. The velocities of these surface waves are in qualitative agreement with theoretical predictions.

86-1788

The Effects of Variations in Sound Speed on Coupling Coefficients between Acoustic Normal Modes in Shallow Water Over a Sloping Bottom

M. Hall
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J. Acoust. Soc. Amer., 79 (2), pp 332-337 (Feb 1986) 9 refs

KEY WORDS: Underwater sound, Sound waves

The conventional method for determining the coupling coefficient between acoustic normal modes in shallow water over a hard sloping bottom gives an incorrect result. It assumes the derivative normal to the bottom to be equal to the depth derivative. This problem can be circumvented by measuring depth normal to the bottom.

86-1789

Transient Radiation from Axially Symmetric Sources

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J. Acoust. Soc. Amer., 79 (2), pp 273-277 (Feb 1986) 6 figs, 13 refs

KEY WORDS: Sound waves, Wave radiation, Modal analysis

A method is presented for the efficient calculation of radiated acoustic fields from a radially symmetric source in a rigid baffle excited by an arbitrary time excitation. The technique is a modal analysis based on the series expansion of the source velocity excitation in terms of either of two basis functions. Each mode is propagated by the technique with rapid convergence of the solution evident in 30 or less terms, allowing rapid and efficient computer-based solutions to be obtained. Several numerical field simulations are given.

86-1790

Near-grazing, Low-frequency Propagation Over Randomly Rough, Rigid Surfaces

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J. Acoust. Soc. Amer., 79 (3), pp 657-665 (Mar 1986) 14 figs, 1 table, 14 refs

KEY WORDS: Sound waves, Wave propagation, Point source excitation, Surface roughness

When a low-frequency point source radiates sound close to a low-roughness, steep-sloped, rigid surface, multiple coherent forward scatter creates a boundary wave which propagates with cylindrical divergence and dispersion in the fluid region near the surface. Measurements using laboratory models of surfaces with two- or three-dimensional roughness elements, and a generalization of periodic roughness theory, have been used to develop empirical formulas which described the amplitude and phase velocity of the coherent boundary wave over natural, randomly rough, rigid surfaces. The formulas are stated in terms of the average height and the rms slope of the steep-sloped roughness elements.

86-1791

Evaluation of the Feasibility of Scale Modeling to Quantify Wind and Terrain Effects on Low-Angle Sound Propagation

G.S. Anderson, R.E. Hayden, A.R. Thompson, R. Madden
Bolt Beranek and Newman, Inc., Cambridge, MA

Rept. No. NASA-CR-172488, BBN-5516, 128 pp (Jan 1985) N86-15056/2/GAR

KEY WORDS: Sound waves, Wave propagation, Scaling, Wind-induced excitation, Ground surface

The feasibility of acoustical scale modeling techniques for modeling wind effects on long range, low frequency outdoor sound propagation was evaluated. Upwind and downwind propagation was studied in 1/100 scale for flat ground and simple hills with both rigid and finite ground impedance over a full scale frequency range from 20 to 500 Hz. Results are presented as 1/3 octive frequency spectra of differences in propagation loss between the case studies and a free-field condition. Selected sets of these results are compared with validated analytical models for propagation loss, when such models were available.

86-1792

Acoustic Radiation of Structures Immersed in an Initially Quiet Gaseous Medium (Rayonnement Acoustique de Structures Plongees dans UN Gaz Initiallement au Repos)

Y. Ousset, N. Sayhi
Centre Technique des Industries Mecaniques, Senlis, France

Rept. No. CETIM-11-R-030, 50 pp (Sept 1984) N86-15064/6/GAR (in French)

KEY WORDS: Sound waves, Wave radiation, Harmonic excitation

The pressure field radiated by a vibrating body immersed in an infinite medium is studied. The potential industrial applications include acoustic sources, noise attenuation and acoustic measurement. The equations suppose a harmonic excitation and a sound wave propagation in an obstacle-free medium A finite element numerical approximation of the Helmholtz equation solution is described. A computer program in which the first phase of computation determines the potential densities by solving a variational formulation is described.

SHOCK EXCITATION

86-1793

Computer Aided Servohydraulic Test Rigs for Earthquake Simulations

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Statens Provningsanstalt, Boras, Sweden

Rept. No. SP-RAPP-1985:28, 25 pp (1985) PB86-125085/GAR

KEY WORDS: Seismic tests, Computer aided techniques

This report covers earthquake testing research by using automated equipment simulation models. Earthquake motions either in the ground or in a building are characterized by the low-frequency contents, typically 1-33 Hz. This implies large displacements and the only way to produce such motions is using servohydraulic actuators. Earthquake testing by applying a true earthquake motion is not correct. If the equipment is mounted in a building, the dynamic behavior of the building must be accounted.

86-1794

Floor Response Spectrum Method for Seismic Analysis of Multiply Supported Secondary Systems

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Earthquake Engrg. Struc. Dynam., 14 (2), pp 245-265 (Mar-Apr 1986) 7 figs, 6 tables, 19 refs

KEY WORDS: Seismic response spectra, Equipment-structure interaction, Pipelines, Floors

Fundamental principles from structural dynamics, theory of random processes and perturbation techniques are used to develop a new method for seismic analysis of multiply supported secondary subsystems, like piping attached to primary structures. The method provides a decoupled analysis of the secondary subsystem wherein the response is given in terms of response spectra associated with the attachment points. Numerical comparisons with exact results are used to examine the accuracy of the proposed method and to demonstrate the importance of the characteristics mentioned above. In all cases examined, the proposed method shows excellent agreement with exact results. By accounting for the effect of interaction, the proposed method leads to more realistic and economical design criteria for secondary subsystems.

86-1795

Experimental Impulsive Method Determining Some Dynamic Properties of Linear Viscoelastic Materials

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Strojnicky Casopis, 37 (1), pp 99-112 (1986) 2 figs, 1 table, 30 refs (in Czech)

KEY WORDS: Impulse testing, Viscoelastic media

In this paper, an experimental technique is described, by which some basic properties of linear viscoelastic materials such phase velocity attenuation coefficient and loss factor could be derived. The method is based on the affine similarity of divergent longitudinal strain pulses by the propagation in a thin long bar made of the linear viscoelastic material. It is shown that the unknown properties of the viscoelastic bar may be determined from the change in shape of strain pulses which travel in the bar.

86-1796

Impact with Friction

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J. Appl. Mech., Trans. ASME, 53 (1), pp 1-4 (Mar 1986) 3 refs

KEY WORDS: Impact response, Friction

A theory of the impact or collision of two rigid bodies, taking account of friction, is presented. It determines how the direction of sliding varies during the impact, which must be known to calculate the direction of the frictional force and thence the frictional impulse. This is accomplished by analyzing the equations of motion of the bodies during the collision The normal impulse is determined by using a coefficient or restitution. When the direction of sliding is constant throughout the collision, the theory agrees with that give by Whittaker, which is correct only in this case.

86-1797
Obstacles as Probes of the Blast Wave Interior in the NRL Laser/Hane Simulation Experiment
J.L. Giuliani, Jr.
Naval Research Lab., Washington, DC
Rept. No. NRL-MR-5671, 36 pp (Dec 1985)
AD-A162 535/9/GAR

KEY WORDS: Shock waves, Cavitation

It is proposed that small obstacles be placed in the path of the expanding blast wave to probe the dynamics of the interior cavity formed after a laser target interaction. The theory of attached and detached shocks for cones and spheres in supersonic streams is briefly reviewed. Graphs of the results for a ratio of specific heat gamma = 1.2 and 5/3 are presented for estimating the local Mach number in the cavity from the experimental results. It is also suggested that theoretical and numerical models of the experiment predict the temporal evolution of the bow shock stand off distance for a blunt obstacle. A direct comparison with the experiment can then verify or rule out the competing models.

86-1798
The Mechanisms of Determining Shock Locations in One and Two Dimensional Transonic Flows
D. Nixon, Y. Liu
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J. Appl. Mech., Trans. ASME, 53 (1), pp 203-205 (Mar 1986) 1 fig, 1 ref

KEY WORDS: Shock wave propagation

The mechanism that locates a shock wave in a transonic flow in one- and two-dimensions is examined. It is found that in one dimension the shock is located by specifying the downstream pressure whereas in two dimensions the shock is located by the application of an entropy condition at the sonic line.

86-1799
A Coupled Finite Element/One-Dimensional Wave Model of Stress Wave Propagation in a Shock Tube
W.J.T. Daniel
Univ. of Queensland, Queensland, Australia
Computers Struc., 22 (4), pp 583-587 (1986) 9 figs, 1 table, 6 refs

KEY WORDS: Finite element technique, Stress waves, Wave propagation, Shock waves

A finite element model coupled to a numerical representation of one-dimensional wave propagation is used to model stress wave propagation in the structure of a large shock tunnel. Modeling difficulties and the method of coupling the two types of model are described. Results are presented which indicate that stress wave damper rods, attached to the tunnel, are effective as a means of controlling stress levels.

86-1800
Blast Wave Reflection Trajectories from a Height of Burst
T.C.J. Hu, I.I. Glass
Univ. of Toronto, Toronto, Canada
AIAA J., 24 (4), pp 607-610 (Apr 1986) 3 figs, 16 refs

KEY WORDS: Shock waves, Wave reflection, Explosives

Consideration is given to an explosive charge (TNT) detonated at various heights of burst above a perfect reflecting planar surface in air. Variations of the incident shock Mach number of the spherical blast wave front as it decays and the corresponding wedge angle are plotted on a two-dimensional shock wave reflection transition map in the plane. It is shown that all four types of shock wave reflection (regular, single Mach, complex Mach, and double Mach) can occur in a free-air explosion. However, if the height of burst is increased past a certain limit, only two types of shock wave reflection can occur (regular and single Mach).

86-1801
Shock Waves in Transonic Channel Flows at Moderate Reynolds Numbers
J.L. Mace, T.C. Adamson, Jr.
Air Force Wright Aeronautical Labs., Wright-Patterson Air Force Base, OH
AIAA J., 24 (4), pp 591-598 (Apr 1986) 6 figs, 20 refs

KEY WORDS: Shock waves

The behavior of shock waves in transonic channel flows with varying Reynolds and Prandtl numbers is examined using analytical and numerical methods. It is shown that the location of a sonic line within the structure of a shock wave is independent of the Reynolds number and coincident with the corresponding discontinuous wave location in the limit as the Reynolds number tends to infinity. Also, in a numerical solution, truncation errors and artificial viscosity produce a smeared shock wave similar to that found in a flow at a moderate Reynolds number. Thus, these results lend support to the commonly accepted supposition that the position of the sonic line within the structure of a numerical shock wave can be adopted as the location of the corresponding shock wave in inviscid flow.

86-1802
Pseudo-Stationary Mach Reflexion of Shock Waves
F. Seiler
Institut Franco-Allemand de Recherches, Saint-Louis, France
Rept. No. ISL-CO-216/85, 15 pp (Jul 1985)
PB86-126919/GAR

KEY WORDS: Shock waves, Wave reflection, Wedges, Monte Carlo method

The pseudo-stationary oblique shock wave reflection, by a wedge was numerically investigated by the direct Monte Carlo simulation technique. In the numerical study the real gas flow is simulated at the molecular level by using a large number of model particles following their positions in phase space. In order to simulate the shock reflection from a wedge, a two-dimensional computational model was set up. The incident shock wave is generated by a piston, which is suddenly set in motion and then moving into the flow at constant velocity.

VIBRATION EXCITATION

86-1803
Finite Element/Difference Methods in Random Vibration
F.S. Wong
Weidlinger Assoc., Palo Alto, CA
Computers Struc., 23 (1), pp 77-85 (1986) 4 figs, 11 refs

KEY WORDS: Random vibrations, Finite element technique, Finite difference technique

Finite element and finite difference analyses of a class of random vibration problems are presented. The random field equations are discretized using the standard finite element/difference techniques. Recursive algorithms for the moments of the response in terms of the moments of the random loading and random initial condition are derived based on the discretized equations. The approach is straightforward and it provides an alternative to the standard normal-mode approach in the analysis of linear random structural systems. However, unlike the standard approach, the finite element/difference approach can be applied to other more complex systems. Two numerical examples are given to illustrate the application. The approximate numerical results are also compared with the exact solutions to check the accuracy of the finite element/difference analyses. It is found that for the problems considered, the finite difference algorithms provide better accuracy and efficiency than the finite element method.

86-1804
A Primer of Random Vibration Techniques in Structural Engineering
P.D. Spanos, L.D. Lutes
Rice Univ., Houston, TX
Shock Vib. Dig., 18 (4), pp 3-9 (Apr 1986) 30 refs

KEY WORDS: Random vibrations, Reviews

A review of random vibration techniques for analyzing dynamic systems is presented from the perspective of applicability to structural engineering. Problems involving linear or nonlinear, elastic or inelastic structural models are addressed.

86-1805
Random Variation of Modal Frequencies: Experiments and Analysis
T.L. Paez, L.J. Branstetter, D.L. Gregory
Sandia National Labs., Albuquerque, NM
Rept. No. SAND-85-1379C, 28 pp (1985)
DE86000434/GAR

KEY WORDS: Natural frequencies, Fundamental frequencies, Cantilever beams, Random vibrations

The purpose of this investigation is to establish an analytic technique for the estimation of the second order statistical moments of modal frequencies when one or more underlying structural parameters are random variables. The results of a simple laboratory experiment are summarized to show that the analytic technique yields accurate results in a particular case. The analytical investigation summarized here shows that the moments of modal frequencies can be defined in terms of some simpler measure of structural characteristics. The second order moments of a structural system can be evaluated approximately. Some examples are presented.

86-1806
Fluid Slosh Studies Volume 1, Study of Slosh Dynamics of Fluid Filled Containers on Three-Axis Stabilized Spacecraft
H.G. Beig

ERNO Raumfahrttechnik G.m.b.H., Bremen, Fed. Rep. Germany
Rept. No. ESA-CR(P)-2077-V-1, 84 pp (Nov 1984) N86-14549/7/GAR

KEY WORDS: Sloshing, Fluid-filled containers, Spacecraft, Liquid rocket propellants

The problems of the localization of fluid monopropellants in spacecraft tanks are documented. A mathematical formulation and an approximate solution of the cross section of the equilibrium shapes of the liquid surfaces is given. Sample calculations are performed on a tank of type TV-SAT, and guidelines for propellant management devices are derived. In order to obtain mechanical analogs for the dynamic calculation of coupling between liquid motion and spacecraft motion, as input for the attitude control system, use of simplified models of liquid motion was considered. However, the low degree of accuracy because of necessary approximations, and the difficulty in estimating model accuracy, make comparison with experiment necessary. Experiment designs for low gravity tests are given.

86-1807
Vibrational Stabilizability of Nonlinear Systems
R. Bellman, J. Bentsman, S.M. Meerkov
Univ. of Southern California, Los Angeles, CA
Rept. No. CONF-840758-1, 6 pp, (Jul 1984) IFAC World Congress, Budapest, Hungary, DE84-013472/GAR

KEY WORDS: Nonlinear systems, Stability

Conditions of vibrational stabilizability of a trivial solution for nonlinear systems are given. Several examples based on the classical equations of the theory of oscillations are discussed.

86-1808
Random Vibration of System with Finitely Many Degrees of Freedom and Several Coalescent Natural Frequencies
E. Lubliner, I. Elishakoff
Technion--Israel Inst. of Tech., Haifa, Israel
Intl. J. Engrg. Sci., 24 (4), pp 461-470 (1986) 2 figs, 9 refs

KEY WORDS: Random vibrations, Natural frequencies, Multidegree of freedom systems

This study deals with random vibration of a system with finitely many degrees of freedom and two sets of eigenvalues: a single separate one representing the natural frequency of a single-degree-of-freedom structure -- and all the others, which are coalescent. It is shown that as the number of degrees of freedom tends to infinity, the error introduced by omission of the cross-correlation terms reaches 70 percent.

86-1809
Nonstationary Vibration of a System with Backlash Passing through a Resonance
S. Yanabe, H. Tokuhashi, A. Tamura
Technological Univ. of Nagaoka, Nagaoka, Japan

Bull. JSME, 29 (248), pp 533-540 (Feb 1986) 15 figs, 1 table, 13 refs

KEY WORDS: Resonance pass through, Backlash effects

When a system with backlash is subjected to an exciting force, passes through a resonance, nonstationary responses of the system are numerically analyzed and formulas for estimating the maximum amplitudes of the responses are proposed. The evaluation errors are below 25 percent over the range considered here comparing to the numerically integrated results. The above formulas are derived from a comparison of the two maximum amplitudes, one of which is obtained from a response curve calculated by integrating the equations of motion of the backlash system and the other from the estimation equations of the maximum amplitude for a linear systems passing through a resonance.

MECHANICAL PROPERTIES

DAMPING

86-1810
The Dynamics of Dry Friction Damped Systems
A.A. Ferri
Ph.D. Thesis, Princeton, Univ., 246 pp (1985) DA8529034

KEY WORDS: Coulomb friction, Harmonic excitation, Frequency domain method

The need to increase the passive damping of lightly damped mechanical systems has prompted the present study of the dynamics of dry friction damped systems. Dry friction damping has received considerable interest from the designers of turbomachinery and aerospace structures as a means of suppressing free vibration, limiting structure response to forced excitation, and improving the stability of potentially unstable systems. In this thesis, several types of dry friction damped systems are considered. Single and multiple-degree-of-freedom systems under harmonic excitation are studied analytically using traditional, one harmonic techniques and non-traditional, multi-harmonic techniques. Results are compared with time integration results and with experimental results. It is found that frequency domain techniques can be very effective in studying the behavior of dry friction damped systems. In particular, it is seen that a substantial improvement in accuracy can be obtained by including higher harmonics in the analysis.

FATIGUE

86-1811

Fracture Energy Analysis Via Acoustic Emission

L.I. Maslov, O.M. Gradov

A.A. Baikov Inst. of Metallurgy, Moscow, USSR

Intl. J. Fatigue, 8 (2), pp 67-71 (Apr 1986) 5 figs, 10 refs

KEY WORDS: Acoustic emission, Fatigue life

The results of previous studies on acoustic emission during fatigue loading are used to relate the characteristics of the acoustic signals to the fracture processes occurring at the crack tip. At stresses below the yield point of the material, discrete acoustic emissions are produced, their amplitude distribution being described by a monotonically decreasing function. At stresses near the yield point, the signals are continuous with a peak observed in the amplitude distribution function, while above the yield point the acoustic emission resumes the character it has below the yield point. It is shown that these emissions correspond to the formation of individual microfractures, to the process of macroplastic deformation and to stepwise crack propagation of the structurally disordered material, respectively.

86-1812

A Spectral-Analysis Method for Nonstationary Field Measurements

M.K. Abdelhamid, K.G. McConnell

Iowa State Univ., Ames, IA

Exptl., Mech., 26 (1), pp 47-55 (Mar 1986) 10 figs, 1 table, 9 refs

KEY WORDS: Spectrum analysis, Fatigue life

A method for dealing with the problem of spectral analysis of nonstationary field measurements is presented. The method hypothesizes that the nonstationary signal consists of two stationary signals which belong to different populations (environment and working plus environment) which occur consecutively. The analysis method entails segmenting the time history and estimating the population of each segment. Two estimators are presented (average absolute value and energy in a frequency band) and their frequency characteristics are described. Discrete-Fourier transforms of zero-padded segments are used for estimating the spectral-density functions. This method is simply implemented and treats the problem of smoothing the spectral estimates. Moreover, it simplifies the use of different window functions by using convolution in the frequency domain. This paper describes the computational facilities used as well as some electronic circuits that were developed.

86-1813

A Further Study on Fatigue Crack Initiation Life — Mechanical Model for Fatigue Crack Initiation

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Northwestern Polytechnical University, Xian, Peoples Rep. China

Intl. J. Fatigue, 8 (1), pp 17-21 (Jan 1986) 6 figs, 26 refs

KEY WORDS: Fatigue life, Crack propagation

In the present study, a new formula for the fatigue crack initiation life is developed based on recent progress in the study of fatigue damage and crack initiation, and is substantiated experimentally. The new formula reveals a correlation between the fatigue crack initiation life, the notched element geometry, the cyclic loading condition, the tensile properties and the fatigue crack initiation threshold, which is indicated as an important parameter in describing the fatigue damage and crack initiation. The correlation between the fatigue crack initiation threshold, the endurance limit and the tensile properties is also given. The threshold for fatigue crack initiation can be obtained by the regression analysis of the fatigue crack initiation life test data without any additional test.

86-1814

Discrete Crack Modelling for Dynamically Loaded, Unreinforced Concrete Structures

P.E. Skrikerud, H. Bachmann

Structural Engineering AS, Oslo, Norway

Earthquake Engrg. Struc. Dynam., 14 (2) (Mar-Apr 1986) 31 figs, 16 refs

KEY WORDS: Concrete, Crack propagation, Finite element technique

The dynamic response of unreinforced concrete structures is studied taking account of initiation, extension, closing and reopening of so-called discrete cracks. The computational procedure is based on the finite-element method and is at present restricted to two-dimensional situations. The discrete cracks are simulated by separation of originally adjacent finite elements. An equivalent tensile-strength criterion is used for the initiation and extension of the cracks which are assumed to propagate perpendicularly to the principal tensile stress. If this direction does not coincide with the interelement boundaries of the finite-element mesh, the latter is automatically altered. Between elements being separated by a crack special crack elements are introduced, which take account of the stress transfer by aggregate interlock. The equations of motion are integrated numerically using an explicit formulation. The procedures outlined are demonstrated on a simplified cross-section of a concrete gravity dam subjected to horizontal earthquake excitation.

86-1815

Nonlinear Analysis of Crazes

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Texas A&M Univ., College Station, TX

J. Appl. Mech., Trans. ASME, 53 (1), pp 97-102 (Mar 1986) 7 figs, 17 refs

KEY WORDS: Cracked media, Hysteretic damping

This paper concerns the nonlinear mechanical behavior of a single craze of finite length contained in an extended linear elastic medium. The craze is modeled as a distributed spring with a nonlinear force-displacement relation, which exhibits a hysteresis loop upon unloading. Stresses, displacements, and energy release rates are computed and compared against results for a linear craze. The case of a central crack within the craze is also considered.

EXPERIMENTATION

MEASUREMENT AND ANALYSIS

86-1816

An Expert System for Real-Time Noise and Vibration Analysis of Shipboard Equipment

S.K. Klein, J.A. Vail, K. Balon

ORI, Inc.

Naval Engr. J., 98 (3), pp 107-114 (May 1986) 7 figs

KEY WORDS: Shipboard equipment response, Machinery vibration, Signature analysis, Computer programs, Expert systems

An expert system is described which allows real-time analysis of the noise and vibration signature of vibrating machinery. The system presented consists of an adaptive algorithm which varies the band width of analysis channels as a function of a signal complexity factor and a measure of the rapidity of local signal change. Overall program architecture is presented as well as detailed discussion of signature functional identification and statistical trend modules which are adaptable to a wide variety of input data base configurations. Results are presented of program execution on Navy hydrophone and propulsion gas turbine data showing current signature and projections of trend to future times compared with failed condition signatures. Correlation results for such predictions are also discussed.

86-1817

Characterization of Sound Field Parameters of Ultrasonic Probes Using a Computer-Controlled Measurement and Data Acquisition System

A. Erhard, H. Fuchs, W. Mohrle, P. Matscholl

Federal Inst. for Materials Testing, Berlin

NDT Intl., 18 (6), pp 359-362 (Dec 1985) 7 figs, 6 refs

KEY WORDS: Ultrasonic techniques, Proximity probes

Sound fields of ultrasonic probes can be investigated using a computer-controlled measurement and data acquisition system. The equipment can automatically measure parameters such as the angle of refraction, angle of divergence and skewing angle. Non-contact electrodynamic microphones are used for directivity pattern measurements and sound field mapping. The system is now in operation in the FRG to help produce more soundly based requirements for probe parameters and tolerances.

86-1818

What Does "Sensitivity" Mean?

W. Tustin

Tustin Inst. of Tech., Santa Barbara, CA

Test., 48 (2), pp 28-29 (Apr/May 1986) 3 figs

KEY WORDS: Measuring instruments, Vibration measurement, Calibrating

The term sensitivity as it applies to various kinds of sensors is explained. The interchangeable terms pickup or transducer are discussed. Even though accelerometers are mainly discussed, most points apply equally well to sensors for pressure, force, flow, etc. Both static and dynamic sensitivity and calibration are included.

86-1819
Laser Vibrometer
M.J. Rudd
Dept. of the Navy, Washington, DC
U.S. Patent No. 4 554 836, 6 pp (Nov 1985)

KEY WORDS: Vibration meters, Measuring instruments, Lasers

This patent discloses optical interferometric apparatus for detecting and measuring discontinuities in structural materials from ultrasonic stress waves at their surfaces. The apparatus includes an acousto-optic modulator which shifts a portion of a laser beam in frequency, producing a modulated light beam of light. This modulated light beam is deflected and passes through an adjustable lens to the surface being measured. The light scattered by the surface is focused by the lens of an end mirror of the laser which produced the original beam, and is divergingly reflected therefrom.

86-1820
Special Applications
F.L. Walls, J.J. Gagnepain
National Bureau of Standards (NML), Boulder, CO
Precision Frequency Control, 2 Ch. 15, pp 287-296 (1984)

KEY WORDS: Measuring instruments, Resonators, Quartz crystals, Vibration measurement, Acceleration measurement

The high resolution achievable with frequency metrology often makes it attractive to connect the measurement of physical parameters to a frequency measurement via a suitable transducer. Quartz crystal resonators are sensitive to mass loading and via nonlinear effects, to temperature and stress. The sensitivities are generally low, however, the excellent short-term stability of precision quartz resonators makes high-resolution measurements of temperature, pressure, vibration, acceleration, film thickness, some gas-phase chemical rates, and absorption feasible.

86-1821
Vibration Amplitude Measurement with a Laser Interferometer
R.H. Katyl
IBM Corp., Endicott, NY
Noise Control Engrg. J., 26 (1), pp 44-48 (Jan-Feb 1986) 6 figs, 6 refs

KEY WORDS: Acoustic emission, Electronic instrumentation, Vibration measurement, Amplitude measurement, Interferometric techniques

Emission of acoustical noise at audio frequencies can be produced by many electronic components. This paper describes a laser-interferometric technique that we used to measure sub-optical wavelength vibrational amplitudes of some electronic components. Typical peak amplitudes were 20 nm. With this technique major noise contributors could be identified so that corrective action could be taken. Besides being highly sensitive, the method has the advantage of being non-contacting and non-loading to the device under test.

86-1822
An Orthogonal Decomposition Approach to Modal Synthesis
H. Flashner
Univ. of Southern California, Los Angeles, CA
Intl. J. Numer. Methods Engrg., 23 (3), pp 471-493 (Mar 1986) 10 figs, 5 tables, 35 refs

KEY WORDS: Modal synthesis

Modal synthesis is a method of formulating the equations of motion for complex vibratory systems. This approach has many advantages in modeling systems that consist of an assembly of linear dynamic elements whose modal characteristics are given. Presented in the paper is a procedure for synthesizing linear dynamic models into one dynamic description in a numerically stable way. This task is achieved by an orthogonal coordinate transformation replacing the matrix inversions required when other procedures are used. The modal synthesis approach is formulated as a problem of finding the equations of motion for a linear system subject to a set of linear constraints. The numerical procedure to generate the equations of motion in terms of independent coordinates is presented. The paper concludes with several examples that demonstrate the properties of the proposed method and its application to the modeling of vibratory systems.

86-1823
Double Least Squares Approach for Use in Structural Modal Identification
S.R. Ibrahim
Old Dominion Univ., Norfolk, VA
AIAA J., 24 (3), pp 499-503 (Mar 1986) 1 fig, 6 tables, 16 refs

KEY WORDS: Parameter identification technique, Modal analysis, Ibrahim time domain technique, Time domain method, Least squares method

In their procedures, several time domain modal identification algorithms encounter the solution of an overdetermined system of equations, usually by using the method of least squares. Such a method of solution is known to have statistically biased errors that can severely affect the identification accuracy, especially for the damping factors. A double least squares solution is presented and shown to reduce considerably the bias and improve the identification accuracy without a large increase in computational cost. To illustrate the proposed approach, the damping identification accuracy of the time domain modal identification algorithm referred to at the ITD technique is discussed. Simulated identification results show the improved accuracy of the double least squares approach when compared to the ordinary least squares method.

86-1824
Modal Analysis of Nonconservative Systems with Singular Coefficient Matrices
O. Danek
Czechoslovak Academy of Sciences, Prague, Czechoslovakia
Strojnicky Casopis, 36 (6), pp 715-722 (1985) 5 refs (in Czech)

KEY WORDS: Modal analysis, Eigenvalue problems

In the presented contribution the influence of singularity of coefficient matrices on the eigenvalue solution is studied.

86-1825
Solving Vibration Problems Using Modal Analysis
R. Schmidtberg, T. Pal
Aries Technology, Lowell, MA
S/V, Sound Vib., 20 (3), pp 16-21 (Mar 1986) 6 figs

KEY WORDS: Experimental modal analysis, Modal models

The application of analytical and experimental techniques to the solution of structural dynamics problems is reviewed. Analytical techniques include the development of a modal model based on lumped parameter systems and finite element methods. Experimental techniques involve the extraction of modal parameters by dynamically testing the actual structure. The modal model is developed through curve fitting of the experimental data. The analytical and experimental models can be compared and utilized to predict the response of the structure to input forces and to simulate the effects of structural modifications at low cost.

86-1826
Step Relaxation Method for Modal Test Implemented with Frequency-Domain Preprocessing
F.R. Vigneron, Y. Soucy
Communications Research Centre, Ottawa, Canada
AIAA J., 24 (4), pp 657-663 (Apr 1986) 14 figs, 2 tables, 18 refs

KEY WORDS: Experimental modal analysis, Step relaxation method, Frequency domain method

The theory and practical aspects of an implementation of the step relaxation method of modal test that includes preprocessing of data in the frequency domain is presented. The method is demonstrated using a test of a continuous longeron space mast that has several low-frequency closely spaced modes.

86-1827
A Modal Synthesis Method Employing Physical coordinates, Free Component Modes, and Residual Flexibilities
U.A. Bucher
Swiss Fed. Inst. Tech., Zurich, Switzerland
Computers Struc., 22 (4), pp 559-564 (1986) 9 refs

KEY WORDS: Modal synthesis, Component mode synthesis

For the solution of the eigenproblem of large dynamical systems a new component synthesis method incorporating residual flexibilities and free component modes is developed. The assembly procedure for this method is particularly simple, in fact the components can be linked to other components or elements like a conventional finite element by the direct stiffness approach because the reduced component models employ the physical coordinates of the interface nodes among others. Therefore, the method may easily be integrated into an existing finite element code. Convergence is outstanding because the residual flexibilities are considered at the interface degrees of freedom linking the individual substructures. It is believed that the method possesses potential computer applicability because of the listed advantages.

86-1828
Combined Experimental/Analytical Modeling of Shell/Payload Structures
D.R. Martinez, A.K. Miller, T.G. Carne
Sandia Nat. Labs., Albuquerque, NM
Rept. No. SAND-84-2598, 47 pp (Dec 1985) DE86004968/GAR

KEY WORDS: Component mode synthesis, Experimental modal analysis, Spacecraft, Shells, Beams

This study evaluates the accuracy of computed modal frequencies obtained from a combined experimental/analytical model of a shell/payload structure. A component mode synthesis technique was used which incorporated free modes and residual effects. The total structure is physically divided into the two subsystems which are connected through stiff joints. The payload was tested to obtain its free-free-modes, while a finite element model of the shell was analyzed to obtain its modal description. Both the translational and rotational components of the experimental mode shapes at the payload interface were used in the coupling. Sensitivity studies were also performed to determine the effect of neglecting the residual terms of the payload. Results from a previous study of a combined experimental/analytical model for a beam structure are also given. The beam structure was used to examine the basic procedures and difficulties in experimentally measuring, and analytically accounting for the rotational and residual quantities.

86-1829
Criteria for Proper Selection of Sine Sweep Test Parameters
K.H. Haslinger
Combustion Engineering, Inc., Windsor, CT
Test., 48 (2), pp 12-33 (Apr/May 1986) 16 figs, 7 refs

KEY WORDS: Swept sine wave excitation, Pipes, Cantilevers

A series of tests performed on a cantilevered pipe structure dramatically illustrate the potential for large experimental errors when proper sine sweep rates are not selected. These rates can be much lower than those typically cited in various standardized test procedures. To determine accurately the true amplitude response and damping characteristics of a test specimen, sine sweep rates must be used which consider the test structure's inherent damping capacity. Based on numerical simulations of sine sweep cycles for a Single Degree of Freedom Oscillator, the article presents guidelines which enable the test operator to make prudent selections of adequate sine sweep rates and band pass filter selections.

86-1830
Experimental/Analytical Determination of the Real Normal Mode Parameters of a Structure with Limited Accessibility
N. Niedbal
European Space Agency, Paris, France
Rept. No. ESA-TT-839, DFVLR-FB-83-26, 148 pp (Jun 1985) N86-16683/2/GAR

KEY WORDS: Normal modes, Phase separation method

Phase separation methods for the experimental determination of normal mode parameters are proposed. As opposed to the classical phase resonance method, these methods require no adjustment of the exciter forces. In the case of a structure with limited accessibility, such methods improve the experimental modal analysis. A phase separation method is selected and its reliability enhanced for the case of damping coupling. A method to transform complex normal mode parameters into real normal ones is presented.

DYNAMIC TESTS

86-1831
Relative Conservatism and Drop Table and Shaker Shock Tests
T.J. Baca, T.D. Blacker
Sandia Natl. Labs., Albuquerque, NM
Rept. No. SAND-85-1394C, 22 pp (1985) DE86001263/GAR

KEY WORDS: Shakers, Shock tests, Testing techniques

The objective of this paper is to quantitatively compare the relative conservatism of haversine and decaying sinusoid shock test input pulses which are generated on drop tables and electrodynamic shakers. A complete evaluation of test conservatism between the laboratory and field shock environment requires characterization of shock severity and consideration of this characterization's statistical variation. A shock intensity spectrum is introduced as a new shock characterization which provides information on the severity of the shock as a function of frequency. Test conservatism is quantified in terms of an Index of Conservatism and a novel criterion called an Overtest Factor. Accelerometer measurements were made on the fixed end of a cantilever beam structure. Data were gathered from a field shock environment and three laboratory test environments. The laboratory tests included two drop table test series and one decaying sinusoid test series. An analysis of test conservatism was carried out on the data using these new techniques. Results are presented for the case where multiple tests provide a complete statistical basis.

86-1832
Design and Control of a High Velocity, High Force Hydraulic Shock Test Machine
J.D. Favour
Boeing Aerospace Co., Seattle, WA
J. Environ. Sci., 29 (2), pp 54-57 (Mar-Apr 1986) 3 figs, 2 tables

KEY WORDS: Shock tests, Test equiment, Hydraulic systems

This paper discussed the design and control of a large hydraulic shock testing device. The system is capable of peak velocities up to 10.2 m/s (400 in/sec) and peak forces up to 801 kN (180,000 lbs). The major challenges discussed are: the concept design, the specification and procurement of two very large (2500 gpm) electro-hydraulic servovalves, and the failsafe control of the servovalves and system response. The system performance is briefly discussed.

86-1833
Evolution of Emerging Environmental Testing and Evaluation Techniques
A.H. Burkhard
Air Force Wright Aeronautical Labs., Wright-Patterson Air Force Base, OH
J. Environ. Sci., 29 (2), pp 38-42 (Mar-Apr 1986) 2 figs, 52 refs

KEY WORDS: Testing techniques, Environmental effects, Electronic instrumentation

Contemporary statisticelly-based environmental test and evaluation techniques used to develop and qualify electronic systems will be too costly and time consuming for emerging equipment systems. These newer systems have much higher levels of reliability than current systems. The current emphasis on physical testing needs to be reduced and blended with the emerging analytical computerized tools to develop a more cost effective approach to evaluate the environmental suitability of electronic systems. It is proposed that an integrated approach based upon fracture mechanics concepts of latent defects growth and/or a nondestructive inspection technique could yield such an approach.

86-1834
Analysis of Cross-Coupling of a Multicomponent Jet Engine Test Stand Using Finite Element Modeling Techniques
W.G. Schweikhard, W.N. Singnoi
Kansas Univ./Ctr. for Res., Inc., Lawrence, KS

Rept. No. NASA-CR-176424, 55 pp (1985) N86-15323/6/GAR

KEY WORDS: Test stands, Jet engines, Finite element technique, Computer programs

A two axis thrust measuring system was analyzed by using a finite element computer program to determine the sensitivities of the thrust vectoring nozzle system to misalignment of the load cells and applied loads, and the stiffness of the structural members. Three models were evaluated.

DIAGNOSTICS

86-1835
Preliminary Evaluation of Some Gear Diagnostics Using Vibration Analysis
S.C. Favaloro
Aeronautical Res. Lab., Melbourne Australia
Rept. No. ARL/AERORPOP-TM-427, 28 pp (Jul 1985) AD-A161 939/4/GAR

KEY WORDS: Diagnostic techniques, Gears, Time domain method, Frequency domain method, Wear

Several conditions monitoring methods for gears, which use the signal average of gear vibrations in both the time and frequency domain, have been investigated during a 1500 hour test on a gear ring. Results have shown that although heavy wear, in the form of fine pitting and scuffing, occurred over most of the tooth surfaces, the time domain procedures and levels of the fundamental and first harmonic of meshing frequency did not respond to damage to the gears. Total vibration and the ratio of sideband to total energy showed only marginal response to wear.

86-1836
Failure of Turbomachinery Components
P. Lowden, J. Liburdi
Liburdi Engrg., Ltd., Burlington, Ontario, Canada

Turbomachinery Symp., Proc. of the 14th, Texas A&M Univ., College Station, TX (Oct 22-24, 1985) (Spons. Turbomachinery Labs., Dept. M.E., Texas A&M) pp 23-33, 29 figs, 1 ref

KEY WORDS: Diagnostic techniques, Failure analysis, Turbomachinery

The analysis of turbomachinery failures is a highly specialized field requiring a detailed understanding of superalloy metallurgy, moderate and high temperature failure mechanisms and an appreciation of the stresses, excitations and mechanical design characteristics of the various parts. Common failure mechanisms such as creep, fatigue, oxidation, corrosion, and wear are often observed, either singly or in combination, which makes the identification of the primary mode of failure more complex. To assist with the identification of service failures, a review of the principal failure mechanisms is presented along with the associated metallurgical features. In addition, a number of cases are presented to emphasize the need for a cooperative approach to failure analysis in order to translate the metallurgical information to possible mechanical/operational causes and solutions.

86-1837
Review of Fundamental Two Pole Induction Motor Mechanics
C.A. Corey
Louis Allis, Div. of Magnetek, Milwaukee, WI
Turbomachinery Symp., Proc. of the 14th, Texas A&M Univ., College Station, TX (Oct 22-24, 1985) (Spons. Turbomachinery Labs., Dept. M.E., Texas A&M) pp 17-21, 10 figs, 2 tables, 4 refs

KEY WORDS: Diagnostic techniques, Intake systems, Sum and difference frequencies

An introduction to two pole motor mechanics is presented, with the goal of promoting an understanding of normal and abnormal vibration sources to assist in the diagnosis of the field problems of such motors. Motor force vectors are reviewed, which define sample frequencies and magnitudes for the normal mechanical and electrical causes. Tables of sources of both normal and abnormal forces are presented which enable the reader to calculate the frequencies involved and possible causes for excessive levels. Sum and difference frequencies (beat) are complicating factors in such motors and a brief nonmathematical discussion of such processes is presented, in terms of two pole motor vectors. A case problem is presented, showing an example of two pole motor beat frequencies and the associated sidebands in such problems cases.

BALANCING

86-1838
The Dynamic Properties of the Elastic Rotors on the Sliding Bearings and Their Influence on the Choice of the Balancing Procedure
F. Turek, R. Svoboda
Nat. Res. Inst. for Machine Design, Praha-Bechovice, USSR
Strojnicky Casopis, 36 (6), pp 707-715 (1985) 1 fig, 3 tables, 7 refs (in Czech)

KEY WORDS: Balancing techniques, Rotors, Sliding bearings

The possibilities of the optimal balancing of the elastic rotors on the sliding bearings are discussed. It is shown that the choice of the method of balancing can depend on the character of the unbalanced forces. Two different types of mathematical model either the selfadjoint dynamic system or the unselfadjoint one can be considered as decisive for the choice in question.

86-1839
Adjustable Balance Weight for Rotating Shaft
D.J. Wiebe
Dept. of Air Force, Washington, DC
U.S. Patent Appl. No. 4 539 864, 4 pp (Sep 1985)

KEY WORDS: Balancing techniques, Shafts

This patent discloses a balance weight mechanism which is attached to a tubular engine shaft for correcting unbalance in the engine. The tubular shaft includes a stiffener plate mounted therein transversely to the rotational axis of the shaft. The balance weight mechanism includes a balance weight arm and a fastener for releasably fastening an end of the arm to a generally central location on the stiffener plate where the axis of rotation of the shaft intersects the plate. Spline teeth on the balance weight arm face toward the stiffener plate and are aligned to intermesh with an arc of an annular spline ring on the plate for holding the arm in a desired angularly adjusted position extending outwardly radially from the axis of rotation of the shaft when the arm is fastened tightly against the plate.

86-1840
Mass Balancing of Hollow Fan Blades
R.E. Kielb
NASA Lewis Res. Ctr., Cleveland, OH
Rept. No. NASA-TM-87197, 15 pp (1986) N86-16611/3/GAR

KEY WORDS: Fan blades, Balancing techniques, Flutter

A typical section model is used to analytically investigate the effect of mass balancing as applied to hollow, supersonic fan blades. A procedure to determine the best configuration of an internal balancing mass to provide flutter alleviation is developed. This procedure is applied to a typical supersonic shroudless fan blade which is unstable in both the solid configuration and when it is hollow with no balancing mass. The addition of an optimized balancing mass is shown to stabilize the blade at the design condition.

MONITORING

86-1841
Condition Monitoring in Hostile Environments — Seminar Proceedings
ERA Technology Ltd., Leatherhead, England
Rept. No. ERA-85-0118, 217 pp (1985) ERATL-86/05/GAR

KEY WORDS: Monitoring techniques

Papers presented are as follows. A review of condition monitoring. Acoustic leak detection in fossil fuelled boilers. On-line crack detection by acoustic emission monitoring. Condition monitoring in the presence of severe electrical interference. Use of optical fiber sensors for crack detection. Development of a continuous debris monitor. A machine monitoring system for an offshore oil platform. Condition based maintenance in underground applications. The measurement of temperature, density and level in storage tanks containing LNG. SESAME an expert system for condition monitoring and fault analysis. The use of fiber optics in gas turbine applications. Health monitoring in high technology applications. Piezo-electric accelerometers: their development and application. A vibration spectrum monitor for rotating machinery systems.

ANALYSIS AND DESIGN

ANALYTICAL METHODS

86-1842
Patterns at Primary Hopf Bifurcations of a Plexus of Identical Oscillators
J.C. Alexander
Univ. of Maryland, College Park, MD
SIAM J. Appl Math., 46 (2), pp 199-221 (Apr 1986) 28 refs

KEY WORDS: Bifurcation theory

Mathematically, an oscillator is a system of ordinary differential equations with a periodic limit cycle, usually arising from a Hopf bifurcation for a stationary solution. A plexus is a collection of such oscillators, coupled to each other via one-way or two-way communication channels. Plexuses model a wide number of phenomena in the mathematically oriented sciences. The primary Hopf bifurcation theory of such a plexus is developed. There are features of the bifurcating solutions which depend only on the combinatorics of the plexus and not on the details of the individual oscillators. Such features are called the pattern of the bifurcation. The relation of patterns to the modes of small oscillations of mechanical systems is discussed. More detailed information is developed for weak coupling. The theory is used to analyze two particular types of plexuses; viz. rings and lines of oscillators. It is then shown that the structure of a plexus permits numerical bifurcation computations to be made more efficient, compared to straightforward bifurcation computations. A numerical algorithm is developed to this end. The numerical methods are extended to incorporate higher-order information so as to determine whether the bifurcating branch is sub- or supercritical. Finally some effects of detuning are considered.

86-1843
Minimum Transition Values and the Dynamics of Subcritical Bifurcation
Son Tu, E.L. Reiss
Northwestern Univ., Evanston, IL
SIAM J. Appl. Math., 46 (2), pp 189-198 (Apr 1986) 4 figs, 17 refs

KEY WORDS: Bifurcation theory

Perturbation and asymptotic methods are presented for analyzing a class of subcritical bifurcation problems whose solutions possess minimum transition values. These minimum transition values are determined. In addition, the dynamics of the transitions from the basic state to the large amplitude bifurcation states are obtained. The effects of imperfections on the response of the systems are also investigated. The method is presented for two model problems. However, it is valid for a wide class of problems in elastic and hydrodynamic stability, in reaction-diffusion systems and in other applications. In the first problem we obtain subcritical steady bifurcation states for a one-dimensional nonlinear diffusion problem. In the second problem we consider the subcritical Hopf bifurcation of periodic solutions for a higher order van der Pol-Duffing oscillator.

86-1844
Quasi-Periodic Hopf Bifurcation
B.L.J. Braaksma, H.W. Broer
Groningen Rijksuniversteit, Netherlands
Rept. No. ZW-8501, 52 pp (1985) N86-17058/6/GAR

KEY WORDS: Bifurcation theory, Forced vibration

The differential equation of forced oscillators for small damping is studied. The quasi-periodic Hopf bifurcation for the model problem of a quasi-periodic forced oscillator with fixed frequencies is reported as a solution of Stoker's problem.

86-1845
Response Covariance to Multiple Excitations
Masaru Hoshiya, Shigehiko Shibusawa
Musashi Inst. of Tech., Tokyo, Japan
ASCE J. Engrg. Mech., 112 (4), pp 412-421 (Apr 1986) 8 figs, 1 table, 4 refs

KEY WORDS: Multi-degree of freedom systems, Seismic response, Multipoint excitation technique, Recursive methods

This paper describes an effective method of obtaining covariances in recursive form for a multiple-degree of freedom linear structural system subjected to multiple support nonstationary seismic excitations. The study is an extension of a case of a shaking table type excitation to multiple shaking table type excitations. The accuracy and efficiency were numerically justified.

86-1846
Statistical Bounds on Multivariable Frequency Response; An Extension of the Generalized Nyquist Criterion
D.J. Cloud, B. Kouvaritakis
Oxford Univ., England
Rept. No. OUEL-1581/85, 58 pp (May 1985) N86-17045/3/GAR

KEY WORDS: Frequency response, Statistical analysis

Statistical bounds for model parameters and corresponding system frequency response limits are established. The results are extended to multivariable systems to produce an element by element characterization of system uncertainty. This uncertainty representation can be used to develop frequency response bounds on the eigenfunctions of perturbed multivariable systems, thus producing system gain and phase information via a generalized Nyquist analysis. An application of the technique using two-input/two-output system is presented.

86-1847
Extremes of Gaussian Processes with Bimodal Spectra
G.R. Toro, C.A. Cornell
Risk Engineering, Inc., Golden, CO
ASCE J. Engrg. Mech., 112 (5), pp 465-484 (May 1986) 7 figs, 2 tables, 17 refs

KEY WORDS: Normal density functions, Power spectral density functions, Monte Carlo method

An approximate solution is developed for the extreme-value distribution of a stationary Gaussian process with a spectral density function that exhibits two well-separated modes. Processes of this type arise in the analysis of the combined dynamic response to two loads or to one load that excites two of a structure's modes of vibration. Spectral moments of each of the modes taken separately are used to characterize the process; two envelope processes are then used to approximate the extreme value distribution. The proposed distribution is compared with other approximations and with results from Monte Carlo simulations.

86-1848
Design-Oriented Identification of Critical Times in Transient Response
R.V. Grandhi, R.T. Haftka, L.T. Watson
Wright State Univ., Dayton, OH
AIAA J., 24 (4), pp 649-656 (Apr 1986) 12 figs, 3 tables, 13 refs

KEY WORDS: Time-dependent parameters, Search techniques, Least squares method, Spline technique

This paper describes three techniques for reducing the computational effort involved in identifying critical time points. The first approach is an adaptive search technique, well suited for a slowly varying, exactly known response. The second technique, which is useful for noisy response, is based on approximating the response using least-squares splines. The third approach, suited for highly oscillatory response, is based on grouping closely spaced local peaks to identify a single superpeak. The error incurred due to superpeak switching is compared with the errors due to commonly employed constraint approximations. Two example problems are considered to demonstrate the computational efficiencies of the proposed techniques.

86-1849

Superposition of Linear and Nonlinear Dynamical Systems

L. Pust
Institut of Thermomechanics, Czechoslovakia
Strojnicky Casopis, 36 (6), pp 693-706 (1985) 9 figs, 5 refs (in Czech)

KEY WORDS: Method of superposition

The method of superposition of the dynamic properties of complex system consisting of linear and nonlinear subsystems with one or many degrees of freedom is derived. Dynamic properties of the entire structure as well as of the subsystems are given by the receptance response curves in the chosen points. The response curves of the nonlinear subsystems are calculated by equivalent linearization method, which corresponds to the measuring of the first harmonic component at the experimental tests. The verification of the superposition method is carried out on the example of the beam on nonlinear supports.

86-1850

An Algorithm for Exact Eigenvalue Calculations for Rotationally Periodic Structures

F.W. Williams
Univ. of Wales Inst. of Science and Tech., Cardiff, Wales, UK
Intl. J. Numer. Methods Engrg., 23 (4), pp 609-622 (Apr 1986) 3 figs, 18 refs

KEY WORDS: Eigenvalue problems, Stiffness matrices, Periodic structures

An existing algorithm ensures that no eigenvalues are missed when using the stiffness matrix method of structural analysis, where the eigenvalues are the natural frequencies of undamped free vibration analyses or the critical load factors of buckling problems. The algorithm permits efficient multi-level substructuring and gives exact results when the member equations used are those obtained by solving appropriate differential equations. This paper extends this algorithm to cover rotationally periodic (i.e. cyclically symmetric) three-dimensional structures which are analyzed by using complex arithmetic to obtain a stiffness matrix which involves only one of the rotationally repeating portions of the structure. Nodes and members are allowed to coincide with the axis of rotationally periodicity and the resulting modes are classified. Rigid body freedoms are accounted for empirically, and the exact member equations and efficient multi-level substructuring of the earlier algorithm can be used when assembling the stiffness matrix of the repeating portion.

86-1851

Exact Eigenvalue Calculations for Structures with Rotationally Periodic Substructures

F.W. Williams
Univ. of Wales Inst. of Science and Tech., Cardiff, Wales, UK
Intl. J. Numer. Methods, Engrg., 23 (4), pp 695-706 (Apr 1986) 5 figs, 9 refs

KEY WORDS: Eigenvalue problems, Stiffness matrices, Periodic structures

The theory presented enables rotationally periodic (i.e. cyclically symmetric) three-dimensional substructures to be included when using existing algorithms to ensure that no eigenvalues are missed when the stiffness matrix method of structural analysis is used. A substructure can be connected in any required way to a parent structure which shares its rotational periodicity, or can be connected by nodes at each end of its axis of periodicity to any parent structure. The competitiveness of the method is illustrated by approximate predictions of computation times and savings for two structures which contain rotationally periodic substructures.

86-1852

Fast Fourier Transformation Algorithms: Experiments with Microcomputers

B.W. Conolly, O.F. Hastrup
SACLANT ASW Res. Ctr., La Spezia, Italy
Rept. No. SACLANTCEN-SM-182, 15 pp (Sep 1985) AD-A161 915/4/GAR

KEY WORDS: Fast Fourier transform, Harmonic analysis, Microcomputers

This describes experiments intended to exploit the potential of modern microcomputers for harmonic analysis. Its findings are a contribution to the discussion of how far modern microcomputers can complement, compete with, and, in certain circumstances, substitute for the mainframe. Harmonic analysis is fundamental to signal processing which, in turn, has many applications both in civilian and military contexts. The publication of so-called Fast Fourier Transform algorithms revolutionized digital analysis: results which had previously required many hours of computation could be obtained in minutes. Microcomputers cannot yet compete with mainframes in terms of speed but they do have the important advantages of portability and lower cost. Experience show that equipment exists which combines the advantages of speed and an accuracy adequate for contaminated data, with portability, availability, and versatility that are characteristic of the microcomputer.

86-1853
Dynamic Analysis and Control Synthesis of Integrated Mechanical Systems
C.G. Liang
Ph.D. Thesis, Univ. of Iowa, 190 pp (1985) DA8527981

KEY WORDS: Control simulation

A general methodology for dynamic analysis and control synthesis of integrated mechanical/control/hydraulic systems is presented. A control/hydraulic simulation program is developed for either independent simulation of control systems or integral simulation of controlled mechanical systems in conjunction with a general mechanical systems simulation program. The system topology is automatically identified by processing a symbolic loop matrix that represents the algebraic relationship between the internal control node variables. This process yields a minimal set of state variables resulting in more efficiency in numerical calculations.

MODELING TECHNIQUES

86-1854
Modelling of Stochastic Fields of Dynamic Loadings
J. Cacko, M. Bily
Slovak Academy of Sciences, Bratislava, Czechoslovakia
Strojnicky Casopis, 36 (6), pp 673-680 (1985) 3 figs, 4 refs (in Slovak)

KEY WORDS: Mathematical models, Stochastic processes

The authors present a method of modeling of values of dynamic loadings (forces, stresses, deformations, displacements, accelerations, etc.), obtained from the experiment or service as a field of discrete data with a statistically random character. This method may be used in laboratory simulation of various service loadings when predicting the life of structures or their components.

86-1855
Approximate Finite Element Models for Structural Control
K.D. Young
Lawrence Livermore Natl. Lab., CA
Rept. No. UCRL-93310, CONF. 851209-5, 22 pp (Aug 1985) IEEE Conf. Decision and Control, Ft. Lauderdale, FL, Dec 11, 1985, DE86001582/GAR

KEY WORDS: Finite element technique, Mass matrices, Stiffness matrices, Active control

Approximate finite element models are developed for the purpose of preserving the tridiagonality of the mass and stiffness matrices in the state space model matrices. These approximate models are utilized in the design of active structural control laws for large flexible structures.

PARAMETER IDENTIFICATION

86-1856
Identification of Mechanical Systems Under Stochastic Excitation
J. Giergel, T. Uhl
Krakow Tech. Univ. of Mining and Metallurgy, Krakow, Poland
Strojnicky Casopis, 37 (1), pp 63-76 (1986) 7 figs, 18 refs (in Russian)

KEY WORDS: System identification techniques, Mathematical models, Stochastic processes

This paper shows possibility in building a mathematical model for mechanical systems under stochastic excitation. It has been proved, that a model in the form of independent simple harmonic oscillators can be accepted for real mechanical systems modeling. It has been shown that one method for this kind of model parameter estimation is defined on a F-P-K equation base. Real mechanical systems parameters are estimated by using described method. Real mechanical systems parameters are estimated by using described method.

OPTIMIZATION TECHNIQUES

86-1857
Optimization of Structures Under Shock and Vibration Environment
S.S. Rao

Purdue Univ., West Lafayette, IN
Shock Vib. Dig., 18 (3), pp 7-15 (Mar 1986) 90 refs

KEY WORDS: Optimization, Shock response, Vibration response, Reviews

Structural optimization problems involving dynamic response calculations are classified according to the physical nature of the problem and the major behavior constraint considered. This article contains a summary of recent work in each class. Recent research on optimization techniques, including approximate analysis methods, multilevel design techniques, and multiobjective design procedures, is also presented. Structural optimization problems that need further investigation are summarized.

86-1858
The Computer Age and the Usefulness of Old Ideas
P.A.A. Laura
Inst. of Applied Mechanics, Puerto Belgrano Naval Base, Argentina
Shock Vib. Dig., 18 (3), pp 3-5 (Mar 1986) 12 refs

KEY WORDS: Optimization, Finite element technique, Natural frequencies, Reviews

This paper presents a brief discussion of optimization approaches that improve the efficiency of the finite element method. The recently developed k-optimization parameter method for determining natural frequencies and buckling loads is emphasized.

DESIGN TECHNIQUES

86-1859
Effect of Inelastic Behavior on the Analysis and Design of Earthquake Resistant Structures
J. Lin, S.A. Mahin
California Univ., Richmond, CA
Rept. No. UCB/EERC-85/08, NSF/ENG-85025, 164 pp (Jun 1985) PB86-135340/GAR

KEY WORDS: Seismic design, Earthquake resistant structures

The report presents an evaluation of the effect of inelastic deformation on the preliminary analysis and design of earthquake resistant structures. The first part of the study deals with the interaction between ground motion and structural response parameters. The purpose is to provide a more consistent basis for selecting the design earthquake for systems that respond inelastically. Major emphasis is placed on assessing ways to define the damaging potential of a ground motion. The second part of the study involved developing an efficient analysis procedure for use in the preliminary state of design. Response of typical shear-beam type structures in their initial linear elastic mode shape coordinate systems is presented. In the last part of the study, a preliminary investigation of the seismic behavior of non-structural subsystems supported on inelastic structures is performed. The effects of the severity of inelastic deformations, of different hysteretic characteristics of the structure and of the amount of viscous damping of the subsystem are investigated.

COMPUTER PROGRAMS

86-1860
Structural Mechanics Software: NASTRAN. 1970--January 1986 (Citations from NTIS Data Base)
Natl. Technical Information Service, Springfield, VA
Rept. for 1970-Jan 86, 277 pp (Jan 1986) PB86-855996/GAR

KEY WORDS: Computer programs, Bibliography, Transient analysis

This bibliography contains citations concerning NASA's structural analysis technology. Computer software implementation and evaluation, transient analysis of linear and nonlinear structural dynamic systems, and mathematical modeling for structural mechanics are discussed. Applications include the space shuttle, turbofan engine blades, motor component vibrations, missiles, and non-aerospace related analyses.

AUTHOR INDEX

ABSTRACT CATEGORIES

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CALENDAR

OCTOBER

5-8 Mechanisms Conference [ASME] Columbus, OH (ASME)

7-9 2nd International Symposium on Shipboard Acoustics ISSA '86 [Institute of Applied Physics TNO] The Hague, The Netherlands (J. Buiten, Institute of Applied Physics TNO, P.O. Box 155, 2600 AD Delft, The Netherlands, Telephone: xx31 15787053, Telex: 38091 tpddt nl)

14-16 57th Shock and Vibration Symposium [Shock and Vibration Information Center] New Orleans, LA (Dr. J. Gordan Showalter, Acting Director, SVIC, Naval Research Lab., Code 5804, Washington, D.C. 20375-5000 - (202) 767-2220)

19-23 Power Generation Conference [ASME] Portland, OR (ASME)

20-22 Lubrication Conference [ASME] Pittsburgh, PA (ASME)

28-30 1986 41st Mechanical Failures Prevention Group Symposium, Patuxent River, MD (T. Robert Shives, A113 Materials Bldg., National Bureau of Standards, Gaithersburg, MD 20899)

NOVEMBER

3-6 14th Space Simulation Conference [IES, AIAA, ASTM, NASA] Baltimore, MD (Institute of Environmental Sciences, 940 E. Northwest Highway, Mt. Prospect, IL 60056 - (312) 255-1561)

7-14 Turbomachinery Symposium, Corpus Christi, TX (Turbomachinery Laboratories, Dept. of Mech. Engrg., Texas A & M Univ., College Station, TX 77843)

30-5 American Society of Mechanical Engineers, Winter Annual Meeting [ASME] San Francisco, CA (ASME)

DECEMBER

7-12 ASME Winter Annual Meeting, Anaheim, CA (ASME, United Engrg. Center, 345 East 45th Street, New York, NY 10017)

8-12 ASA, Anaheim, CA (Joie P. Jones, Dept. Radiology Sciences, Univ. of California, Irvine, CA 92717)

9-11 ASA Fall Acoustical Show, Anaheim, CA (katherine Cane, ASA Show Manager, Amer. Inst. of Physics, 335 E 45th St., New York, NY 10017)

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JANUARY

12-15 AIAA 25th Aerospace Sciences Meeting, Reno, NV

FEBRUARY

24-28 SAE International Congress "Excellence in Engineering," Cobo Hall, Detroit, MI (SAE Engrg. Activities Div., 400 Commonwealth Drive, Warrendale, PA 15096)

MARCH

10-12 Power Plant Pumps Symposium [Electric Power Research Institute], New Orleans, LA (Electric Power Research Institute, 3412 Hillview Avenue, Palo, Alto, CA 94304)

6-9 **56th International Modal Analysis Conference** [Union College and Imperial College of Science], London, England (IMAC, Union College, Graduate and Continuing Studies, Wells House -- 1 Union Ave., Schenectady, NY 12308)

6-8 **AIAA 28th Structures, Structural Dynamics and Materials Conference**, Monterey, CA

9-10 **AIAA Dynamics Specialist Conference**, Monterey, CA

JUNE

2-4 **11th Annual Meeting** [Vibration Institute], St. Louis, MO (Dr. Ronald L. Eshleman, Director, Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254)

8-10 **AIAA 19th Fluid Dynamics, Plasma Dynamics and Laser Conference**

29-2 **AIIAA/SAE/ASME/ASEE 23rd Joint Propulsion Conference**, San Diego, CA

AUGUST

31-2 **Twentieth Midwestern Mechanics Conference (20th MMC)**, Purdue University, West Lafayette, IN (Professors Hamilton and Soedel, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907)

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AHS American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA American Institute of Aeronautics and Astronautics
1633 Broadway
New York, NY 10019

ASA Acoustical Society of America
335 E. 45th St.
New York, NY 10017

ASCE American Society of Civil Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

ASLE American Society of Lubrication Engineers
838 Busse Highway
Park Ridge, IL 60068

ASME American Society of Mechanical Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

ASTM American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

ICF International Congress on Fracture
Tohoku University
Sendai, Japan

IEEE Institute of Electrical and Electronics Engineers
United Engineering Center
345 E. 47th St.
New York, NY 10017

IES Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IMechE Institution of Mechanical Engineers
1 Birdcage Walk, Westminster
London SW1, UK

IFToMM International Federation for Theory of Machines and Mechanisms
U.S. Council for TMM
c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA Instrument Society of America
67 Alexander Dr.
Research Triangle Pk., NC 27709

SAE Society of Automotive Engineers
400 Commonwealth Dr.
Warrendale, PA 15096

SEM Society for Experimental Mechanics (formerly Society for Experimental Stress Analysis)
7 School Street
Bethel, CT 06801

SEE Society of Environmental Engineers
Owles Hall
Buntingford, Hertz.
SG9 9PL, England

SNAME Society of Naval Architects and Marine Engineers
74 Trinity Pl.
New York, NY 10006

SPE Society of Petroleum Engineers
6200 N. Central Expressway
Dallas, TX 75206

SVIC Shock and Vibration Information Center
Naval Research Laboratory
Code 5804
Washington, D.C. 20375-5000

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PUBLICATION POLICY

Unsolicited articles are accepted for publication in the **Shock and Vibration Digest.** Feature articles should be tutorials and/or reviews of areas of interest to shock and vibration engineers. Literature review articles should provide a subjective critique/summary of papers, patents, proceedings, and reports of a pertinent topic in the shock and vibration field. A literature review should stress important recent technology. Only pertinent literature should be cited. Illustrations are encouraged. Detailed mathematical derivations are discouraged; rather, simple formulas representing results should be used. When complex formulas cannot be avoided, a functional form should be used so that readers will understand the interaction between parameters and variables.

Manuscripts must be typed (double-spaced) and figures attached. It is strongly recommended that line figures be rendered in ink or heavy pencil and neatly labeled. Photographs must be unscreened glossy black and white prints. The format for references shown in **Digest** articles is to be followed.

Manuscripts must begin with a brief abstract, or summary. Only material referred to in the text should be included in the list of References at the end of the article. References should be cited in text by consecutive numbers in brackets, as in the following example:

> Unfortunately, such information is often unreliable, particularly statistical data pertinent to a reliability assessment, as has been previously noted [1].
>
> Critical and certain related excitations were first applied to the problem of assessing system reliability almost a decade ago [2]. Since then, the variations that have been developed and practical applications that have been explored [3-7] indicate . . .

The format and style for the list of References at the end of the article are as follows:

- -- each citation number as it appears in text (not in alphabetical order)
- -- last name of author/editor followed by initials or first name
- -- titles of articles within quotations, titles of books underlined
- -- abbreviated title of journal in which article was published (see *Periodicals Scanned* list in January, June, and December issues)
- -- volume, issue number, and pages for journals; publisher for books
- -- year of publication in parentheses

A sample reference list is given below.

1. Platzer, M.F., "Transonic Blade Flutter -- A Survey," Shock Vib. Dig., 7 (7), pp 97-106 (July 1975).

2. Bisplinghoff, R.L., Ashley, H., and Halfman, R.L., Aeroelasticity, Addison-Wesley (1955).

3. Jones, W.P., (Ed.), "Manual on Aeroelasticity," Part II, Aerodynamic Aspects, Advisory Group Aeronaut. Res. Dev. (1962).

Articles for the **Digest** will be reviewed for technical content and edited for style and format. Before an article is submitted, the topic area should be cleared with the editors of the **Digest.** Literature review topics are assigned on a first come basis. Topics should be narrow and well-defined. Articles should be 3000 to 4000 words in length. For additional information on topics and editorial policies, please contact:

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THE SHOCK AND VIBRATION DIGEST

Volume 18, No. 9 September 1986

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